# ASSESSMENT OF DEGRADATION OF EQUIPMENT AND MATERIALS IN RELATION TO SUSTAINABILITY MEASURES

BY



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# Abstract

Sustainability is the one of the newest design considerations in building construction. Current programs of sustainability such as Energy Star for buildings and LEED, are providing methods to reduce operational energy use and encourage sustainable building materials. While these methods do aid in building sustainability, a more encompassing method of analysis has been provided with Life cycle Analysis. Life Cycle Analysis aims to provide a complete method of carbon accounting for the life of the building. This accounting includes the construction of the building through the occupancy and even the demolition and removal of waste.

When predicting the used carbon for a building in the future, current methods are to use a linear analysis method. The objective of this paper is to introduce entropy into the analysis, and review the total impact. This natural degradation of the building and equipment will change the performance throughout the life of the building. A dynamic degradation model is investigated in this research. With degradation, equipment will use 27.3% more electrical use at the end of life, with at total energy use increase of 15.6%. This increase is important to be included in total building energy accounting for accuracy.

## Acknowledgements

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# Chapter 1 Background

Sustainability in the field of engineering is a recent development. Historically, engineering emerged to solve the current needs of society and industry. The progress of this work was successful, but it came at a price. The energy used by buildings has been increasing over the decades, which has contributed to the increasing levels of carbon dioxide on the planet (Plass, Fleming and Schmidt 2010). This has been indicated as one of the sources of climate change. The realization that energy use has generated a direct impact on the environment forces policy makers and businesses to consider how to balance the delivery of the required service while reducing fossil fuel consumption through increased efficiency.

There is a need for greater accuracy in the modeling of environmental impact of buildings. Current methods review the building as if they do not reflect the reality and do not consider, the nature of entropy. The modeling of this natural entropy is needed to improve the accuracy of the environmental impact analysis. The purpose of this research is to determine what is needed for this additional modeling.

### 1.1 Foundation of Sustainability Research

Research in the late 1950's started to show the potential impact of climate change. After the Second World War, scientists started to realize that carbon dioxide ($CO_2$) produced from fossil fuel consumption was not fully absorbed through natural means and that the atmosphere was gaining excess $CO_2$ which was not being eliminated. The

Keeling Curve, developed in 1958, was the first attempt to continuously monitor carbon in the atmosphere to find its long term trend (Briggs 2007). This curve, which is still being updated, has shown a significant and steady increase in the atmospheric carbon since the start of data collection (Earth System Research Laboratory, NOAA 2013). Plass et al (2010) determined that $CO_2$ buildup would create an insulation layer for infrared light. They estimated that $CO_2$ generated from the burning of fossil fuels could raise the global temperature by 2 degrees Fahrenheit per century (Plass, Fleming and Schmidt 2010). This rise in carbon was also confirmed by research on ice core samples, and by the carbon absorption dating of trees. The mounting evidence indicated human activities were the primary cause for increasing CO2 in the atmosphere. Such scientific research, along with other relevant research conducted afterward, was not fully disseminated to the general public until the late 1980's. Thus very few in the general public knew about the effects of $CO_2$ on the global climate before this time.

The increasing public desire for the federal government to reduce environmental impacts resulted in the National Environmental Policy Act of 1969. The Council on Environmental Quality, which was tasked to make environmental assessments for all federal agencies, was created by the act. These assessments were to confirm and set oversight on all federal agencies to ensure that environmental issues had equal weight in the decision making progress (U.S. Department of Energy 2012). The Federal Environmental Administration was reorganized by executive order into the Environmental Protection Agency (EPA). In this reorganization, the Council on Environmental Quality was administered by the EPA (Farrah 1992). The EPA was placed in charge of enforcement of various environmental laws and charged to conduct research related to pesticides, industrial waste, water pollution, and air pollution (The Council on Environmental Quality 2012). Since then the EPA has redirected its focus on sustainability and developed market oriented programs like Energy Star and Water Sense (Farrah 1992)**.**

### 1.2 Government Legislation to Research and Regulate Environmental Damage

The 1970's in the United States reached peak domestic oil production, however the oil embargo made the public aware how energy needs could have an impact on the economy and the U.S. dependence on oil. Although the oil embargo lasted for a short time, it showed how heavily reliant the United States was on the use of fossil fuels, and heightened the need for new energy sources (Anders 1980). In response to this and public outcry, the Federal Energy Administration was formed in 1974 to manage the collection and research of energy data for the United States. Congress passed the Department of Energy Organization Act, which combined the Federal Energy Administration (FEA) and the Atomic Energy Commission into the Department of Energy (DOE) in 1974 (Farrah 1992). In 1977, the Energy Information Administration was formed to continue the research, analysis, and reporting of energy information for the government under the DOE (Farrah 1992).

### 1.3 ASHRAE Standard 90 – Sustainability Though Economic Regulation

Standard 90 aims at making buildings more energy efficient. This standard was originally developed during the early 1970's when the United States was hit by domestic peak oil production, and in reaction to the 1973 Oil Embargo (Oklahoma Society of Professional Engineers 2010). The public was most concerned with the price of energy and the industry responded. The market reacted by focusing on new sources of cheap energy and increasing supplies. With up to 34% of a commercial building's energy use being used for climate control, the American Society of Heating Refrigeration and Air-conditioning Engineers (ASHARE) decided to provide a standard to reduce energy use in buildings. ASHRAE standard 90-1975, *Energy Standard for Buildings* set standards for reduction of energy use within Heating, Ventilation, and Air Conditioning (HVAC) system design. This was a landmark attempt to develop a standard for energy reduction that can be used to aid energy reduction in buildings. The standard was updated in 1980, fixing issues that were found from practice with the 1975 version (Hyderman 2006). In 1989, Standard 90 was split into two volumes; Standard 90.1 *Energy Standard for Buildings Except Low-Rise Residential Buildings* and Standard 90.2 *Energy Standard for Low-Rise Residential Buildings*. The language was changed for use with enforceable codes. The Energy Policy Act of 1992 set efficiency standards for commercial equipment, and made ASHRAE 90.1 a standard that all states must enforce on their commercial buildings as long as the federal government provided funds for enforcement (U.S. Department of Energy 2012). Standard 90.1-1989 was to be enforced on all federal buildings per Section 305 of the act, the states used ASHRAE 90.1 either as the basis or as an enforceable standard within their jurisdiction (Hyderman 2006). This made

ASHRAE 90.1 the de facto energy efficiency code. Other versions were issued in 1999, 2001, 2004, 2007, and 2010 using new methods to reduce energy use, such as life-cycle cost, whole building envelope, and equal cost effectiveness. Each update is set to reduce energy use in buildings by 30% of the current average above previous updates (ASHRAE 2010).

This standard, when enforced by the "Authority Having Jurisdiction," sets the maximum energy use of each installed building energy system. This standard was created to aid in the country's energy independence. The International Code Council's (ICC) International Building Code (IBC), International Green Construction Code (IGCC), and the International Mechanical Code (IMC) have cited ASHRAE 90.1 as its standards for energy efficiencies. Currently, only one state has adopted the most up to date version of 90.1, while 32 states adopted 90.1-2007. These building codes also are only applicable to new construction and major renovations (ASHRAE 2010). Replacing HVAC systems is a costly exercise and most building owners can choose not to replace with an efficient one since ASHRAE 90.1 does not include the replacement of equipment.

### 1.4 The Bruntland Report – The Genesis of Sustainable Development

Sustainability becomes a common term as the publication of the 'Bruntland Report.' The United Nations created the Bruntland Commission in 1983 to understand the reasons behind the global wealth gap between the "North" and the "South." *Our*

*Common Future* was published from this study. The report documented that environmental damage may have been an effect of economic change, and that many of the problems were not regional or local in nature (World Commission on Environment and Development 1987). As a result of this report, the focus of the United Nations came to include social concerns and environmental impacts, rather than economic development alone.

The most important idea to come from *Our Common Future* was the concept of "Sustainable Development." This idea integrates the natural environment and the built environment, to determine a "total solution" that is "sustainable". The report advanced the proposition that sustainability can be advanced by reducing the environmental, economic, and social impacts of human activity.

**1.5 Current Sustainability Legislation**

To continue the public drive of sustainability into the 1990's and beyond, the EPA developed the Energy Star program in 1992. This voluntary program was an attempt to effectively reduce consumer energy use, by establishing the relationship between benefits and energy use (Energy Star 2012). Initially consumer electronics were the main focus of the program, but since 1995, Energy Star moved towards the certification of energy efficient homes. The EPA also set the standard of Energy Star for various building systems, such as HVAC equipment. New standards also are available for consumer appliances, commercial buildings, larger equipment, lighting systems, retail buildings and other building systems.  The Energy Star program continues to target consumer's buying decisions (Energy Star 2012).

The EPA expanded its energy programs into Water Sense in 2006.  Water Sense promotes the reduction of water use through voluntary enforcement of new specifications for faucets or water using fixtures.  The water reduction specifications are for water closets, faucets, urinals, and showerheads.  This program plans to expand into irrigation as well.  Water Sense follows the same idea as Energy Star in which information is provided to the consumers to aid in their buying decisions.

The continuous growth of energy consumption led to the Energy Policy Act of 2005.  Through the Act, subsidies were put in place to promote the development and production of alternative energy sources and solutions (Colker 2008).  Tax credits were also created to assist homeowners to make their homes more energy efficient.  The Energy Independence and Security Act updated these provisions in 2007.  This law required the phasing-out of certain inefficient lighting products and appliances.  The law also required federal buildings to reduce energy use by 30% by 2015 (Colker 2008).  The interpretation of these acts has effectively created a new environment in which designers must operate.  It is now important to analyze the effectiveness of these measures and their effects on sustainability.

# Chapter 2 Introduction to Energy and Carbon Analysis

The 1990's and the years after the turn of the 21st century saw the creation of federal laws that targeted a reduction in energy consumption and carbon emissions. Also achieved was a standardization of goals and measures that enables designers to effectively evaluate the gains in sustainable design. Carbon and energy accounting are especially important to achieve this end. A background of current methods is needed to be reviewed to note how to possibly increase the accuracy of accounting methods.

## 2.1 Basis of Sustainable Analysis

To see if sustainability practices generate gains to society, metrics to measure and analyze efforts are needed. To be measured are economic, environmental and, health impacts. An effective form of sustainability must fulfill all three metrics. The economic value is measured by returns on investment, while at the same time effective forms of sustainability would need to reduce environmental impact benefit society as a whole though the health of the public. These impacts are chosen because of their relationship to the triple bottom line of sustainability, which is a method to evaluate the effectiveness of sustainable measures. This relationship is shown in Figure 2.1.

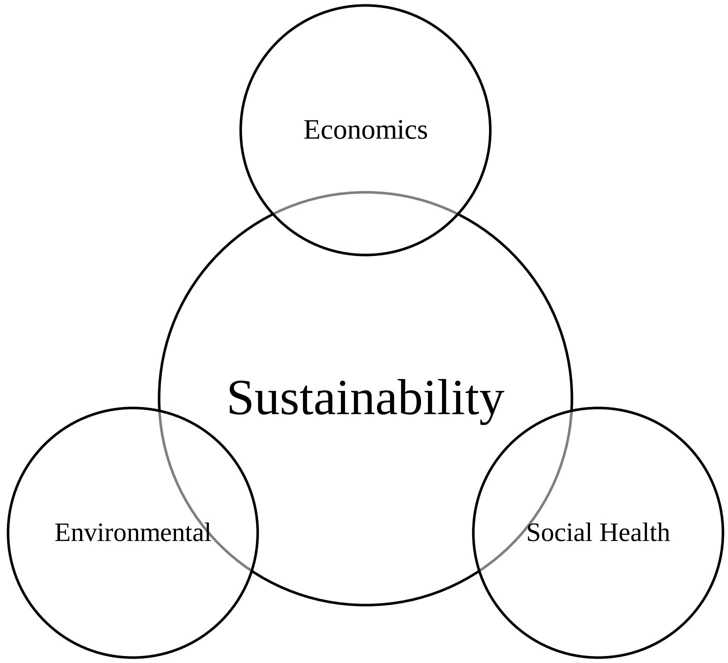



**Figure 2.1 Sustainability's Triple Bottom Line**

A sustainable measure is viewed as an indicator that determines the environmental, social and economic impacts of a product, system, policy or tool. Sustainability means the achievement of the three bottom lines at the same time. This cost aspect is subjective based upon people's values and knowledge.

**2.2 ISO 14000 and Life Cycle Assessment**

ISO 14000 is the standard for Environmental Management Systems that focuses on the processes of an organization. This standard does not aim to reduce the environmental impact of the item, but to allow an organization to model the environmental impact of its processes (Fogler and Timmons 2007). This system is specifically designed for products, and not for buildings, even though it can still be used to manage the construction, operation and maintenance processes of buildings. One of the ISO 14000 series is ISO 14040: Life Cycle Assessment. This standard is the most relevant standard for this research.

Life Cycle Assessment (LCA) is a process of accounting for environmental impacts, such as the consumption of energy and carbon emissions which can be appropriated to view a building life cycle. LCA can be used to track the sustainability of materials and processes of buildings as shown in the following figure (Kwok, et al. 2012).

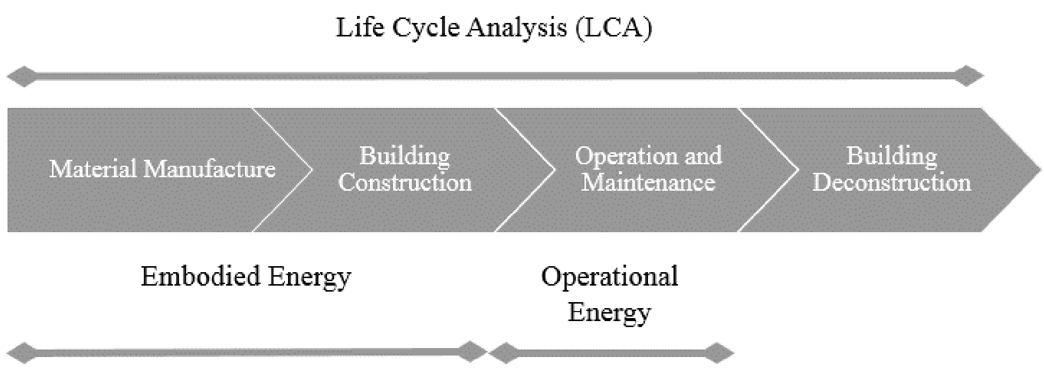



**Figure 2.2 Life Cycle Assessment in Relation to Building Phases** *(Kwok, et al. 2012)*

The key challenge of Life Cycle Assessment is the gathering of the needed data and the reliability of the data (Kwok, et al. 2012). Tracking reliable information becomes extremely difficult when the data falls in the disposal, operation and maintenance stage. Tracking of disposed material is especially problematic.

## 2.3 EIO-LCA

Another method to account for the impact of materials and construction is by using the Economic Input-Output Life Cycle Assessment (EIO-LCA). The EIO-LCA is a method to account for the current scarcity of data within certain areas of the process model (Carnegie Mellon University 2010). This data is derived from economic data involving industries and national studies. In the United States the Department of Commerce (DOC) analyzes multiple economic factors throughout the United States to find the environmental impacts of materials and industries (Carnegie Mellon University 2010). EIO-LCA utilizes the positive effect of a large sample size and detailed data that is already present.

As with the LCA, the system attempts to fully encompass all impacts possible from the manufacturing and construction process. Both systems must create a boundary for analysis. With EIO-LCA, the boundary has been defined by the energy in construction of the item and the transfer of base materials between industries. This creates a strong, analytic method with available data concerning direct and indirect impacts. The system also takes into account most waste in an industry since it totals the amount of material inputted to, and exported from, the system.

Currently, EIO-LCA has three issues that must be resolved. The first is that the data area is too broad. Currently the data acquired can, at best, be reduced to the state level. This is not a problem for states that are geographically small, but is a major issue with larger states such as Alaska and Texas that can encompass multiple climate zones, watersheds, and main power distributors. This affects the analysis of a material's environmental impact. The second issue is that since the data is tied to economic output, all data has to be converted to material units before the data can be used. Data that is set in the material unit's format is still general averages, thus making the data for each individual unit uncertain. This inaccuracy is also present in the material conversion and the timeframe of the data. With a large timeframe and no way to connect the environmental output to specific units, the system assumes a linear distribution. This distribution is not precise since a large number of variables can affect each unit's impact. These could include variables such as qualities of raw materials from different suppliers, the worker's proficiency, weather, and other issues. It should also be noted that the system is calculated by third parties rather than the people doing the analysis, therefore making verification of the calculations difficult.

### 2.4 Embodied Energy/Carbon

Embodied energy is the first part of the energy loop. This covers the energy that was used to extract, transport, and process the materials to the building construction site. This means each piece of construction material in itself, has embodied energy (EE). The embodied energy of the building includes the material EE as well as the installation and construction methods used. Each building then has hundreds, if not thousands of resource lifespans that fall under one overarching analysis. There are databases in which building materials have been analyzed so that the full loop can be calculated. An example of these databases is the Inventory of Carbon and Energy. Each of these databases attempts to find all the leaks and feeds in the system up to the point of shipping of the materials to construction. Concern is that these databases have assumptions within them based on variables such as location, local manufacturing and disposal standards, weather, labor, and other problems.

The embodied energy of a building, includes initial and recurring energy. The initial energy comes from construction of the building to occupancy. Recurring embodied energy occurs within the operation and maintenance of the lifespan of the building and includes replacement of equipment, repair, and upkeep of the building.

**2.5 Operational Energy/Carbon**

Operational energy refers to that section of the operation and maintenance loop used by the occupants of a building. This includes heating, lighting, and equipment use. Energy can come in multiple forms such as electricity, natural gas, and district heating. This energy needs to be catalogued and reviewed with the energy generation methods that were used in production to find the carbon output. A building using on-site alternative energy, would have the energy generation equipment under the embodied energy, while the energy produced would fall under the operational energy (Torcellini and Crawley 2006).

Both embodied and operational energy are linked. Just as owners would install new insulation to lower energy costs, they can increase their embodied energy to reduce their long-term operational energy. With sustainability, the process must address economic sustainability as a standard of practice. It also must fully analyze the embodied carbon and operational carbon to properly reduce the total carbon emissions from the life of the building. Systems are now available to calculate the total carbon of the building and to estimate the total reduction necessary to attain carbon neutral status with reasonable cost and economic rate of return.

### 2.6 Issues with the Current Accounting Methods

Current carbon accounting methods are still in an intermediate state of development, as the processes are still considered as multiple sections of a discipline, instead of one unified field. Evidence can be found in how the current methods of LCA and EIO-LCA separate the embodied and operational carbon even though they look at the total life cycle of the building. This is partly because of politics within the United States where the issue of climate change continues to be debated and has slowed the government's legislation towards a path to sustainable objectives. Currently in place objectives for new buildings to reach net zero energy by 2025 and carbon neutral by 2030, with prior buildings refitted to net zero in 2050 (Crawley, Pless and Torcellini 2009). Each of these objectives has specific guidelines on how the goal is to be achieved.

Currently, accounting methods for net zero buildings only include energy expended from direct operational energy. The system does not take into account other energies that can be caused by the new renewable energy systems or saved by energy audits. The net zero building guidelines do not take into account the resource energy loop on a macro or micro scale (Junnila, Horvath and Guggemos 2006). This system is being seen as a transition point for new buildings to carbon neutrality, and the maximum point for buildings that are new. Net zero is being researched to make the building's operational lifecycle with direct energy economically viable. Therefore a solution to one section of LCA is within reach.

The standards established for federal buildings to be carbon neutral by 2050, only require that no fuels be used that directly produce greenhouse gasses (U. S. Congress 2007). Past research in the field demonstrates this alone will not achieve carbon neutrality. Currently, carbon neutral is based upon the embodied energy from the construction and remodeling phases of the building. This embodied energy is not updated when minor repairs are completed, or during smaller remodels since these are not considered significant. This also does not take into account the operational energy needed to make the repairs. The main question is how we can connect these practices.

### 2.7 Why integrate Embodied and Operational Energy?

The need to integrate the embodied and optional energy for a building is a large step to better understanding sustainability. Each one occurs during one piece of the life cycle of the building and there is no connection or overlap. This issue needs to be addressed before it is possible to fully understand the possibility of a true carbon neutral building.  A new system needs to be based on the total life of the building, not upon arbitrary divisions.

Unlike the lifecycle of a building as shown in Figure 2.2, the reality of the lifecycle is more fluid.  With the embodied energy the current system calculates the total when the material is installed, but does not take into account how the material ages. Some materials will last until the end of the building, while others will degrade without the chance of disposal or recycle.  With the operational aspect of the building, such as renewable energy systems for net zero buildings, there is no attempt to make up the loss of the embodied energy of the equipment for the system, which is not responsible when considering sustainability of a building.  This is fine for current net zero buildings, but since it is being considered as the maximum level attainable by the federal government for current building built before 2030, there needs to be consideration for embodied energy and others related to operations and maintenance.

### 2.8 Energy Degradation and Efficiency Curve

To accurately assess the energy use of a building, we must address the decay inherent in the lifespan of all building systems.  The next step to this integration is the Energy Degradation and Efficiency Curve (EDEC).  EDEC's objective is to advance life-cycle carbon tracking by acknowledging the relationships between embodied and operational energy.

This integration of variables within embodied and operational energy creates a full picture of the total building impact in regards to sustainability. EDEC will be based on a modified version of the resource energy loop. This modified loop does not see each discipline separately, but as actions. For example, the Heating, Ventilation, and Air-Conditioning (HVAC) loop would contain the materials used, the construction energy, operation and maintenance, and the disposal of the system with their associated loops. That means this sub-loop also connects to multiple points within the main loop. This integration will aid in making sustainability less of an individual field, and aid in standardizing sustainability within the disciples of engineering. With this thought process, the LCA can more accurately show the dynamic nature of the two sides of the carbon accounting sections. While this is a different process, which includes life-cycle carbon and energy tracking, the largest difference with EDEC is the analysis of the degradation of the building and its systems.

The degradation section of EDEC is the key to fully analyzing the leaks and gains from an energy loop. Since the material changes within a system are understood for gains and losses, the more intangible issues are accounted for. These intangible sections of an energy loop are related to the ageing of the system. The degradation is important since all parts of a building are subject to entropy, and currently LCA does not acknowledge this change. With the example HVAC loop, the degradation gains and leaks are connected to the failure of the seals and reduction of efficiency with the mechanical units. These efficiency losses add up causing the system to use more energy, thus increasing the environmental impact of the system. Consequently, when considering the total carbon impact of the building, the accounting needs to include the time aspect to correctly attempt carbon neutrality. This system might seem complicated, but EDEC will need support both within and outside the field to be successful.

**2. 9 Net Zero Energy**

Under the DOE, the net zero imitative was an attempt to make buildings that use on average, zero operational energy by 2025 and update older buildings by 2050. The federal description of a net zero building, is where buildings use and produce the same amount of energy. This means only the operational energy of the building is being considered. Other provisions increase energy efficiency of buildings, with federal buildings being carbon neutral by 2030 (Holness 2011).

Currently, net zero energy is based upon utilizing assembled utility data. For many buildings this means the tracking of energy use is, at the minimum based on electrical use and may include natural gas use. Other energy use that could be considered include water transportation and energy used for maintenance and energy for the upkeep of the landscape, although this energy is not as easily verified. Utility data will at the most, track at the monthly level. This can reduce the effectiveness of monitoring energy changes within a building. The question becomes, after the data has been analyzed, how to achieve net zero. This method can be used to achieve net zero energy use or cost. Net zero energy is where the metered energy is equally balanced with energy generated per year, while net zero cost is where the generated energy sold to the utility monetarily equals the cost of energy used (Pless and Torcenllini 2010). Both of these metrics are used depending on how the utility measures the energy put into the grid.

### 2.9.1 Operational Energy Audit

The first priority in building design is to reduce energy consumption. This can be done with a low energy audit on current buildings (Crawley, Pless and Torcellini 2009). A low-energy audit is the process in which buildings have maximized the possible energy savings. With the audits the system is usually set up to maximize the reduction of energy from an economic perspective to convince the owners and operators of the possible savings. Because of this, the low expense options are the favored methods and the large expense items are made as recommendations when the current systems have hit their end of life.

Low expense options can start by changing occupant habits to save energy. This is accomplished by reducing the HVAC, lighting, and electrical systems to the smallest output, while still maintaining the designed use. The thermal capacity of the building envelope would then be increased to reduce energy leakage. Possibly the buildings can be injected with more insulation without major construction, thereby increasing the possible savings. Then equipment is changed only when the simple methods of energy savings are accomplished and the larger cost issues become a necessity. With all this, the building will maximize the potential gains of all renewable energy options.

After the energy audits and the energy saving changes have been accomplished, then the process of designing renewable energy systems for the buildings newer energy use can begin. Depending on the building's location, the design should mix multiple renewable energy sources to increase the reliability of the system in the event that some of the sources cannot run at particular times. Renewable energy systems must be classified into categories to aid in planning for net zero buildings.

### 2.9.2 Net Zero Classifications

The National Renewable Energy Laboratory (NREL) classified sites that try to achieve net zero by what methods are used. These classifications are listed from A to D, with A being the highest accountability with onsite generation and D being the lowest accountability with offsite certificates, as shown in

Table ***2.1*** (Pless and Torcenllini 2010).

**Table 2.1 National Renewable Energy Laboratory Net Zero Classification** *(Pless and Torcenllini 2010)*

| **Net Zero Classification** | **Net Zero Supply Options** | **Net Zero Conditions** |
|---|---|---|
| **A** | Use renewable energy options on building footprint, connected to electrical, HVAC, and water supply systems. | Use without options from Classification B, C, and D. |
| **B** | Use renewable energy options on building site, connected to electrical, HVAC, and water supply systems. | Can use Classification A Methods, cannot use Classification C and D methods. |
| **C** | Use renewable energy options onsite, with importing renewable energy to use with electrical, HVAC, and water supply systems. | Can used Classification A and B Methods, cannot use Classification D methods. |

| | | |
|---|---|---|
| **D** | Purchase accredited Renewable Energy Certificates | Cannot claim Net Zero building site. |

The federal definition of net zero, as shown as renewable energy produced onsite with other renewable energy forms important for offsite areas (Pless and Torcenllini 2010)**.** This means that all energy needs to be produced for the utilization of the building, therefore the energy audit is needed to analysis the needed renewable energy. A higher use of reducing the building's environmental impact is obtained by being carbon neutral.

**2.10 Carbon Neutrality**

Carbon neutrality is a very specific form of net zero energy, established by offsetting the $CO_2$ and $CO_2$ equivalent ($CO_2$e) emissions from the production of energy. This form of neutrality is the simplest form possible since it only covers operational energy. Although to most of the public this is what comes to mind when a carbon neutral building is mentioned, it does not encompasses the full picture. Carbon neutrality accounts for the embodied energy of the building (Junnila and Horvath 2003). This definition is what the federal government means when buildings are required to be carbon neutral by 2050. Embodied energy is the energy needed to make the building. It is agreed that it includes construction, materials, and operation and maintenance needed, but should the construction worker's commute or the occupant's commute be accounted for as well? Environmental impacts pertaining to the building are being called carbon accounting.

### 2.11 Conclusion

The current state of sustainability in regards to life-cycle assessment research is divided into two groups, embodied and operational energy. Both of these areas address most of the carbon accounting process. They have been set as the current standard within the field of sustainability, as shown with ISO 14040 and the drive for carbon neutrality. To increase the analysis methods, EDEC would be used to recognize the degradation of building systems.

## Chapter 3 Research Scope and Methodology

This new form of carbon accounting analyzes the decay from ageing of a building to affect $CO_2$ and energy totals. With all this analysis, the attempts to reduce the energy total can be stated in regards to economic factors. The purpose of EDEC is to account for the degradation of the systems and include this within current analysis methods. The building's energy accounting will need to establish a baseline to analyze the deterioration of the building systems.

### 3.1 Objective of Research

As stated within the discussion of the previous chapter, an additional research method is needed. The process would need to integrate the positives of current systems, such as EIO-LCA, to provide a better result for the end user. This new system would also need to complete certain objectives to be more successful than current methods. These objectives would improve accuracy with the data and its application. The three objectives are as follows:

1. Improve the reliability of data for carbon accounting.
2. Enhance the system for tracking lifecycle energy.
3. Develop methods to extrapolate future trends with the lifespan of the building.

With these objectives, additional analysis can be envisioned to aid in building lifecycle accounting.

The objective of this research is to develop an Energy Degradation and Efficiency Curves (EDEC) which would include a set of impact markers to calculate the total energy and carbon of buildings and equipment. These markers will acknowledge the cohesive nature of these two fields of research and provide a unified direction that will make the impacts of certain choices more prominent than with current methods. With an integrated system including both embodied and operational energy, a more accurate model of a building's lifetime carbon amount can be found, fulfilling the first two objectives of this new process. Also, EDEC will account for the time aspect of degradation to the system with energy efficiency changes and decay of materials. The degradation is important to accurately model building energy accounting. This lifespan carbon analysis needs to reflect the degradation and renewal of certain equipment and how it affects both embodied and operational carbon within the building.

The largest section of EDEC that must be addressed is the degradation of the building and associated system which address objectives 2 and 3. This depreciation curve will attempt to better model the decay of the building compared to the current linear assumptions. With these models completed, we can estimate the total carbon of the building during the design phase so alternative energy production and savings can be researched more in depth for carbon neutral buildings.

This carbon reduction analysis will be compared to construction estimates and operational costs to find not only the total carbon savings but the estimation of costs and paybacks of these systems to determine their economic viability. This could be done in theory through different methods, such as: Photovoltaic solar, solar-thermal, wind energy production, green roofs, carbon capture, and other methods. If long term feasibility is possible with the economics of the system, this new method of long term carbon accounting could become a building standard within national building codes.

### 3.2 Scope

The scope of the research is designed to accomplish additional investigation of carbon/energy accounting of a building, combined with data from previous research of building accounting. With this, we can find the building's total energy use and investigate the depreciation curve of the building within multiple parameters to properly calculate the lifespan carbon and thereby investigate the carbon savings to a constructed building though alternative energy saving and production methods, along with their economic impacts.

### 3.3 Preliminary Model Investigation Process

The EDEC methods are being investigated as a preliminary model to examine the degradation prediction and total building energy calculations. This process will modify and create equations to be used for this purpose. The data required for the prediction models will be based on primary building data and publically available energy use and accounting data. In future surveys of EDEC, not within the current scope of work, longer term building lifespan data track will be investigated. The curves would be supported by real world data, making the predictions more precise and reliable than current laboratory testing. This would aid in maximizing energy savings by combining the energy used in both the operational and embodied energy systems.

### 3.4 Methods

For this research, the process of analysis is divided into three sections; a case study to find the lifetime carbon analysis for the building, analysis of multiple buildings and their individual systems and equipment for depreciation curve along with how they relate to carbon output, and an economic analysis of the current methods on reducing the carbon total. The methods of these investigations for EDEC are divided within two areas; the existing degradation and analysis models with the extrapolation of current data for the prediction of future models, and providing data for these processes.

### 3.4.1 Methods for Design and review of EDEC

To fulfill EDEC, each section of the process will need to be reviewed. With all these processes defined for EDEC, their relationships are defined in Figure 3.1.

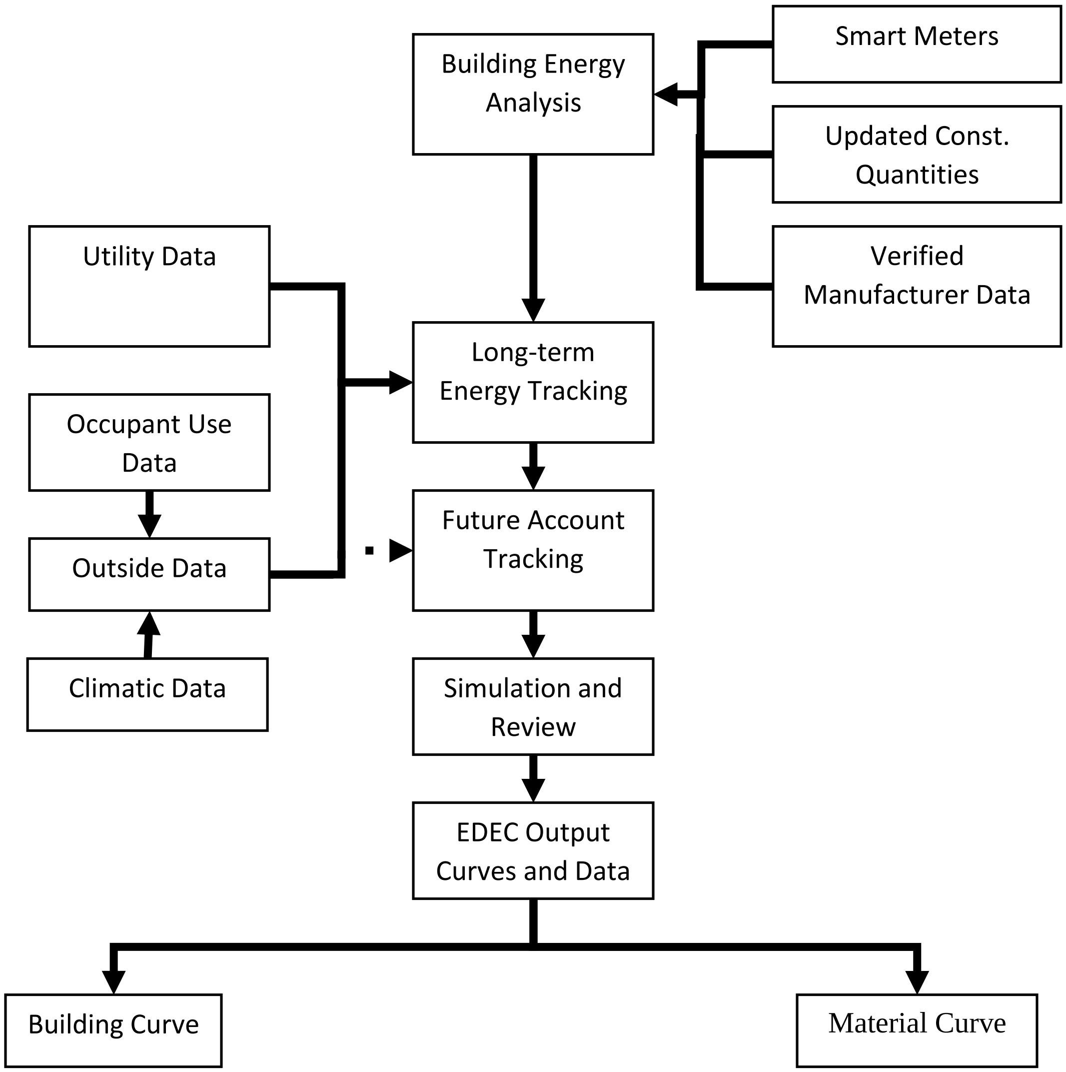



**Figure 3.1 EDEC Processes and Relationships**

As the processes are defined, all the inputs need to be reviewed and considered. The best way to review this system for use would be with a case study. The case study will be conducted by using the materials list for $M^2$SEC, Measurement, Materials and

Sustainable Environment Center on the University of Kansas' campus. The material lists will be combined with the material shipping distances to calculate the embodied carbon totals of $M^2$SEC. Also included in this analysis is the contractor worker schedules to find the carbon produced from worker commutes. The operational energy of the building will be taken from data from the buildings metering system. This operational energy will be combined with the calculated depreciation curve, to accurately calculate the building's lifetime operational carbon total.

### 3.4.2 Integration of Current Energy Accounting with EDEC

The degradation curve in EDEC will be based on analysis of similar buildings built from different eras. These buildings will both catalogue the change in the building's operational energy and the change in embodied energy over time. The operational energy changes will be evaluated on their source, which can be caused by variables such as equipment aging, building envelope leaks, building envelope decay/damage, and poor maintenance. The building's embodied energy change can come from remodeling of the building, material disposal, and material aging and decay. These variables will be reviewed and used to find the variable that affects the building's deprecation curve. With this added to the carbon analysis, the true total carbon for the building can be found. After this total is found, the process to reduce the carbon total through recycling, energy reduction, and energy generation can begin.

The methods to attempt carbon neutrality are the reduction of carbon from materials and energy use, the disposal of material at the end of life, and the production of renewable energy (Crawley, Pless and Torcellini 2009). Each of these methods needs to be combined to find an effective way to negate the carbon made from the life of a building. The reduction of carbon from materials is only effective on new design or remodels, since the materials will not change rapidly throughout the building. The production of operational energy can be used to offset the building's embodied carbon. With these methods, the possible economic impact of the changes to reduce the carbon totals can be calculated. The reduction methods will be reviewed for their impact on carbon reduction total and then on their possible rate of return to see the payback period of these systems, with the site's conditions taken into account. Therefore, the solutions to reducing the building's carbon footprint will also need to reflect the economic issues to fully integrate within the view of the triple bottom line of sustainability (Zuo, et al. 2013).

### 3.4.3 Methods for Building Performance Prediction

With an understanding that equipment and other systems will be repaired and upgraded, the need for future analysis becomes the prediction of these changes within the lifespan of the building and their potential outcomes. This prediction for maintenance and operation of the building would need to be considered accurately. For most predictions the system is linear, therefore not aiding the method being investigated (Salsbury and Diamond 2000).

### 3.5 Data Sources

The data needed for this research will be acquired in multiple ways. The embodied energy data will be based on the Inventory of Carbon and Energy, Version 2.0 – 2006 from the University of Bath. This embodied energy inventory was chosen for the available data pertaining to building materials. Other carbon accounting inventories are not within the scope of this research as only one method is needed for the current analysis. This data will be connected with other sources to do embodied energy calculations for the case studies.

The data for the individual building case study were derived from project management provided by the engineers. For the individual building case study, the data were supplied by the engineers who provided construction project managers. This data cover the majority of the materials that were used in the construction of the building and the contractors' work schedules. This data will be combined with that collected from the building's electrical meter to form a more complete picture of the resource loop of the case building for the calculation of the carbon totals. Other data sources are from the Consumer Building Energy Consumption Survey (CBECS). The building will be compared to operational energy from CBECS to verify assumption of the deprecation curve analysis and model. The data will be discussed in further detail in the following sections.

### 3.4.1 M$^2$SEC

M$^2$SEC on the University of Kansas campus, will be used as a case study for this research. The data comes from JE Dunn who provided construction management for the project. This data is a primary data source for the EDEC process and contains a materials list for the building, papers showing the manufacturing locations of materials and equipment for the building, and the worker schedules for a set number of subcontractors. With this data, the shipping and worker commute distance can be found for use with carbon analysis. The building materials data can be used with ICE to find the carbon, while the transportation carbon will be found with other carbon databases.

### 3.4.2 Consumer Building Energy Consumption Survey

The Consumer Building Energy Consumption Survey is a survey created in 1979 to review the energy use of consumer buildings within the U.S. This survey has been updated multiple times with 2003 being the latest review. The survey is the largest of its type that includes 6,380 buildings with an 82% response rate in 2003 (U. S. Energy Information Administration 2003). The data is provided by the owners of buildings on over 200 variables, that range into multiple areas such as floor space, current use, construction, equipment present, occupancy, age of the buildings, energy conservation measures, energy production sources, and other specifics. This data will be used to review the other operational energy data and if verified, used to fill in missing data on EDEC. The CBECS data will also be used for building assumptions within the depreciation curve for designers and practitioners.

### 3.5 EDEC Simulation Models

For the scope of this research, the fundamental basis of EDEC will be evaluated. The models used will consist of two sets of equipment still in service, of varying ages, and two sets of material curves based on the lifespan of the building. These will be combined to create a building degradation curve that will be compared to current methods of accounting to verify the output. The formulas will be designed to accommodate multiple data sources and model profiles.

### 3.6 Research Questions

Total building energy degradation needs to solve certain questions to be seen as valid in regards to sustainability. The questions, based upon the objective stated earlier, will review the preliminary EDEC method. The questions for this examination are:

1. What are the factors that affect building degradation?
2. Are there any present equations for the factors?
3. Are the equations valid for EDEC use?
4. What data is required for degradation modeling?
5. What is the general formula for total building energy?
6. What is the yearly energy degradation for equipment?
7. What is the lifetime equipment performance degradation?
8. What is the building lifetime degradation totals?
9. What is the remodel embodied energy total?
10. How drastic is the impact of degradation on energy accounting?

11. Should degradation be accounted for based on total impact?

Each question will be answered to examine the validly of using degradation totals. Each item will be addressed to review if degradation totals are needed for certain timeframes or benchmarks. The possible degradation factors will define what data are required for the analysis, providing preliminary methods of review. With these introductory questions answered, the degradation analysis will be investigated by case studies, as commented earlier. Results of final EDEC system model will be presented and compared to current accounting methods for net zero and carbon neutral renewable energy offsetting.

# Chapter 4 EDEC Preliminary Variables and Formulas

For EDEC to predict the changes in life-cycle energy use of a building, a better understanding of what factors affect the performance of buildings is needed. The factors will need to be compared by multiple criteria, with each set established on how the building interacts in relation to time. These factors will be used to define trends or for building comparison use. The criteria on which the factors will be reviewed shall be: the accuracy of the source data, the total effect of the system, the number of data sources, and stability of future predictions. With the variables decided, the curves for each system will need to be calculated and inputted into a master formula to give the user the EDEC prediction for the set time period. This use of data will change the degradation trends for the building, therefore localizing the preliminary prediction model to the building.

## 4.1 Review of EDEC Variables

For a total building system to be reviewed, the issues that affect building performance have to be catalogued. The building performance is directly tied to the construction of the building, its equipment and the environment surrounding the area. To review these variables, each one will be subdivided into how it relates to the performance of the building in respect to the embodied and operational energy. From a review of the issues put forth within the *ASHRAE Handbook*, some of the major variables for operational energy are: efficiency of systems, quality of materials and systems, age of materials and systems, construction quality of the building, the local weather, replacement schedule of systems, and the repair schedule of materials and equipment (ASHRAE 2009). The interconnectivity of the variables is shown in Figure 4.1.

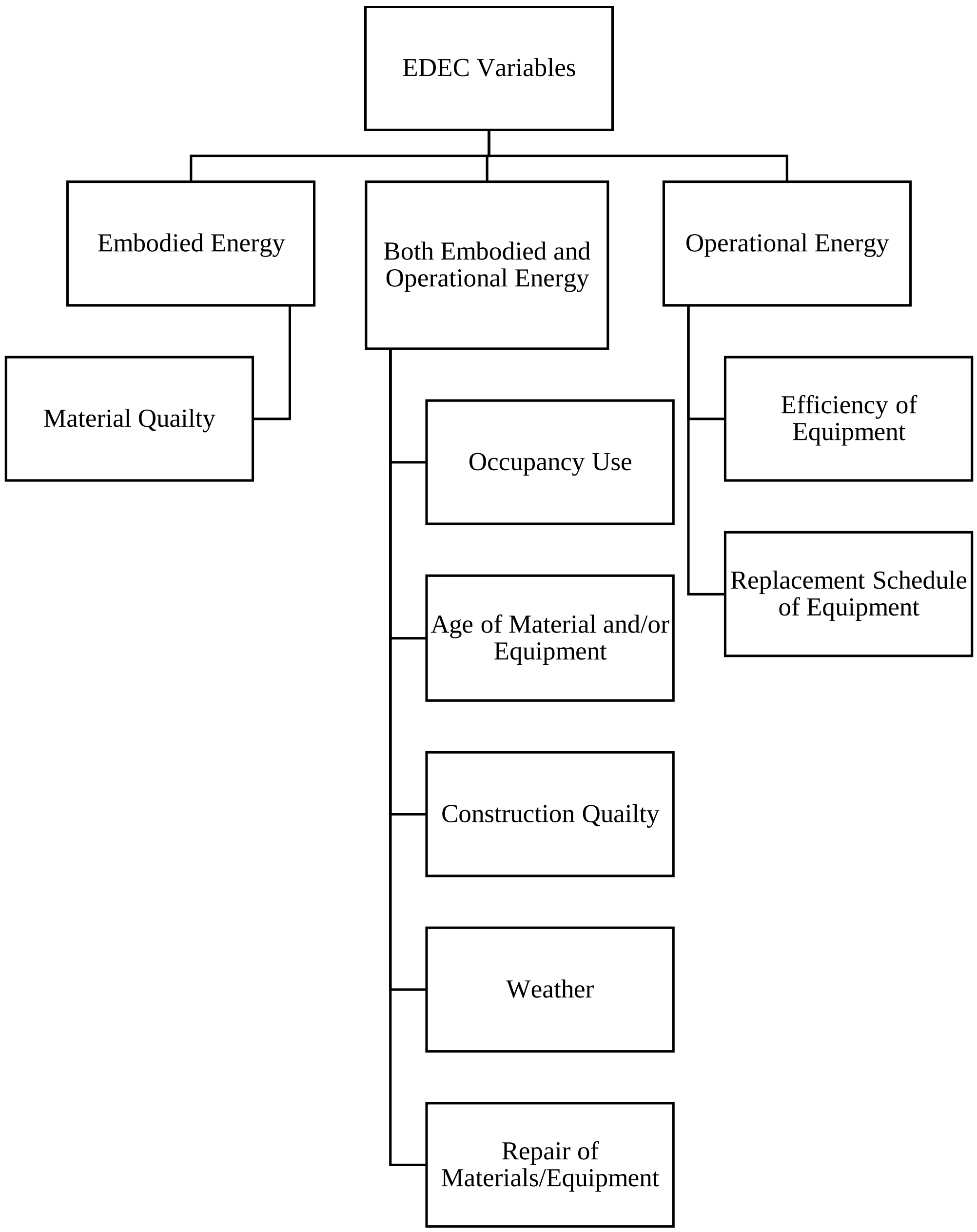



**Figure 4.1 Relationship of Variables Between Embodied and Operational Energy**

As can be seen, many of these variables overlap, causing changes to both the embodied and operational energy of the building. Most of these are directly controlled by the designer, builder, owner, and maintenance personnel. These will be viewed as direct variables, since they are able to be controlled in some manner. The breakdown of the direct and indirect systems are presented in Figure 4.2.

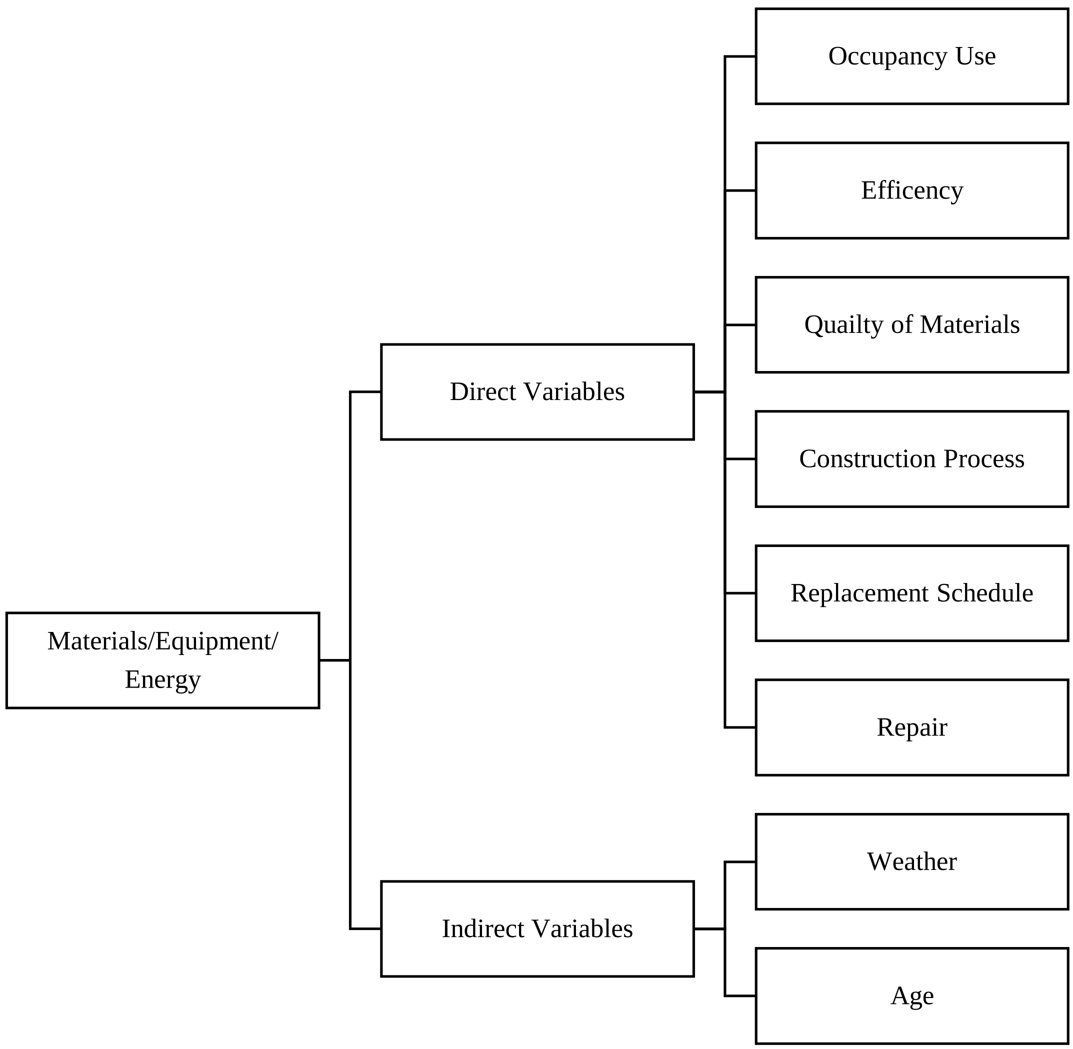



**Figure 4.2 The Direct/Indirect Nature of EDEC Variables**

With the direct variables controlled by the design, construction and upkeep of the building, the gathering of data to compare to other buildings is important. These variables need source data that is kept current for the predictive nature of EDEC. An in depth review of the impacts of the variables on the buildings/systems is needed.

The general EDEC curve results from a combining of factors based on the variables presented from calculation of each dependent system. The total lifespan energy of a building is a combined account of embodied and operational energy from building materials and running of equipment. An example lifespan building curve is shown in Figure 4.3.

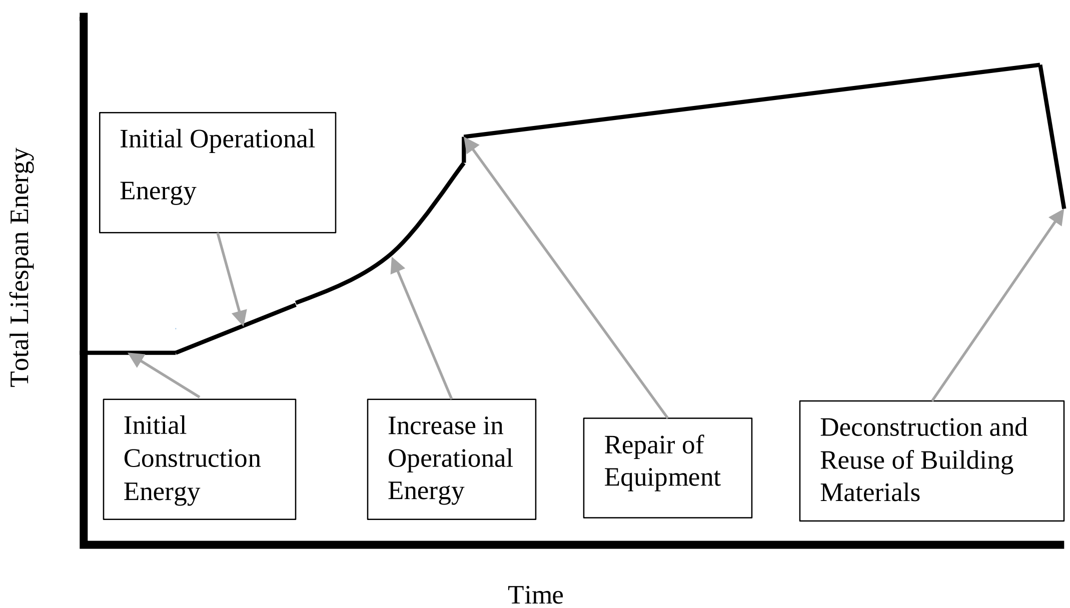



**Figure 4.3 Example Building Lifespan Energy Use**

The curve shows the accumulation of total energy for the building. This energy increases with the building when new material is added and operational energy is used. To reduce the total energy is to create new energy from renewable resources, but the energy to create the renewable system must be accounted for, or to recycle/reuse materials from the building at the end of life. The rate of change of total energy for the building is shown in Figure 4.4.

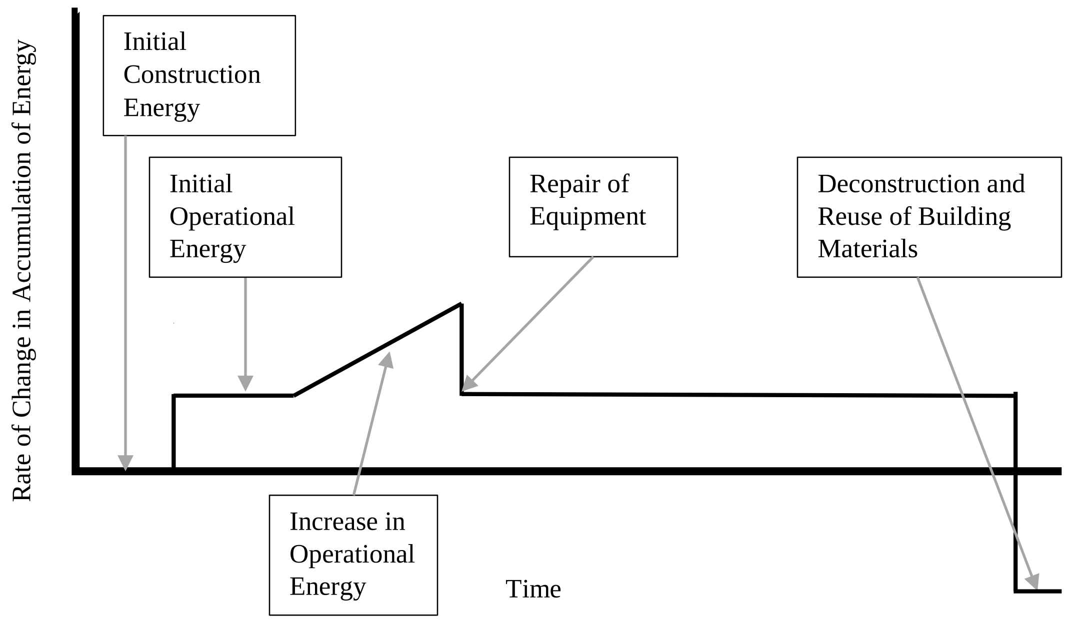



**Figure 4.4 Rate of Change in Accumulation of Building Energy**

The curves are indicative of how the variables within EDEC can affect the total energy of the building. Each of these variables needs to be investigated for its impact on the rate of change in energy accumulation.

## 4.2 Direct Building Preliminary Markers

To complete the factor that will impact the performance of the building throughout its lifespan. The main factors to use for the prediction modeling are directly attributed to the building. Predictive modeling relies on factors directly attributed to the building to assess performance throughout its lifespan. These direct factors affect the total energy for the building and/or modify primary degradation data. These factors are necessary for minimal EDEC. Each factor can be reviewed from primary source data or through calculations form acquired building data. Of these, the direct preliminary building markers are of the highest priority of data collection and estimation.

### 4.2.1 Efficiency of Equipment

Equipment efficiency is important for the accounted operational energy of a building. The efficiency of the building's equipment defines the baseline energy and yearly energy changes, therefore the equipment's change in efficiency could drastically affect the energy used. The efficiency of equipment is defined in the formula:

$$\eta = \frac{W_o}{W_i} \qquad \textbf{(4.1)}$$

Where:

$\eta$ = Efficiency of the equipment

$W_o$= Energy used by the equipment

$W_i$= Energy going into of the equipment

When the efficiency is reduced, more energy is needed to perform the same task. This increases the amount of energy needed. The equipment losses are due to the wear and tear of the equipment from use (Mumma 2003). This can be mitigated to some degree with repairs, but the equipment will still have a reduction of equipment efficiency. The change in efficiency is shown in Figure 4.5.

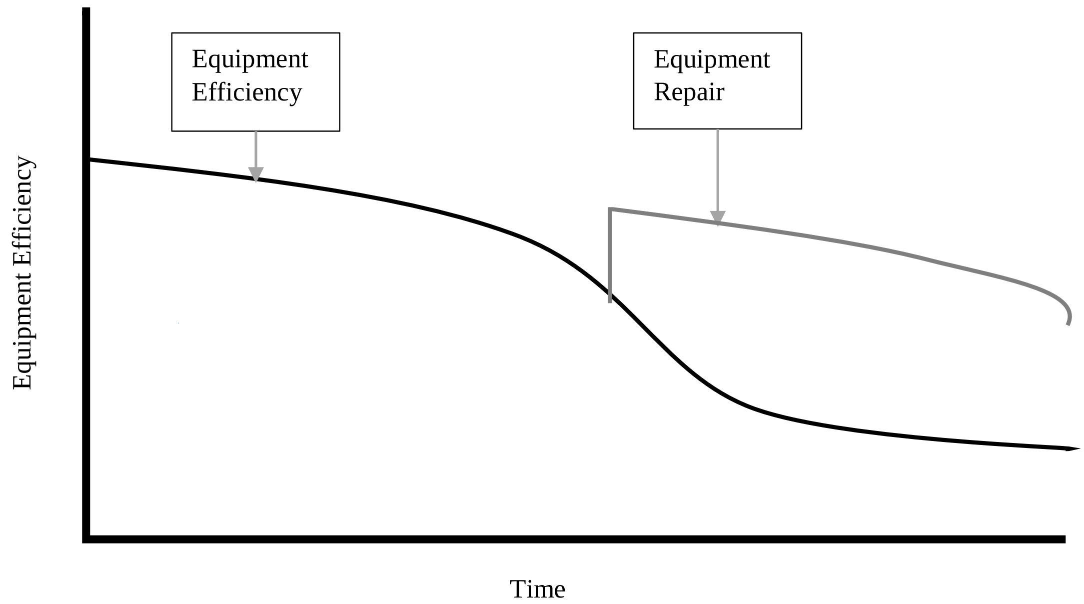



**Figure 4.5 Equipment Efficiency Vs. Time** *(Grussing and Liu 2013)*

### 4.2.2 Repair of Materials/Equipment

The repair of materials and equipment are needed to calculate the embodied energy of the building. When the repairs are done, the embodied energy is changed to reflect the new material added/removed from the building, depicted in the following figure.

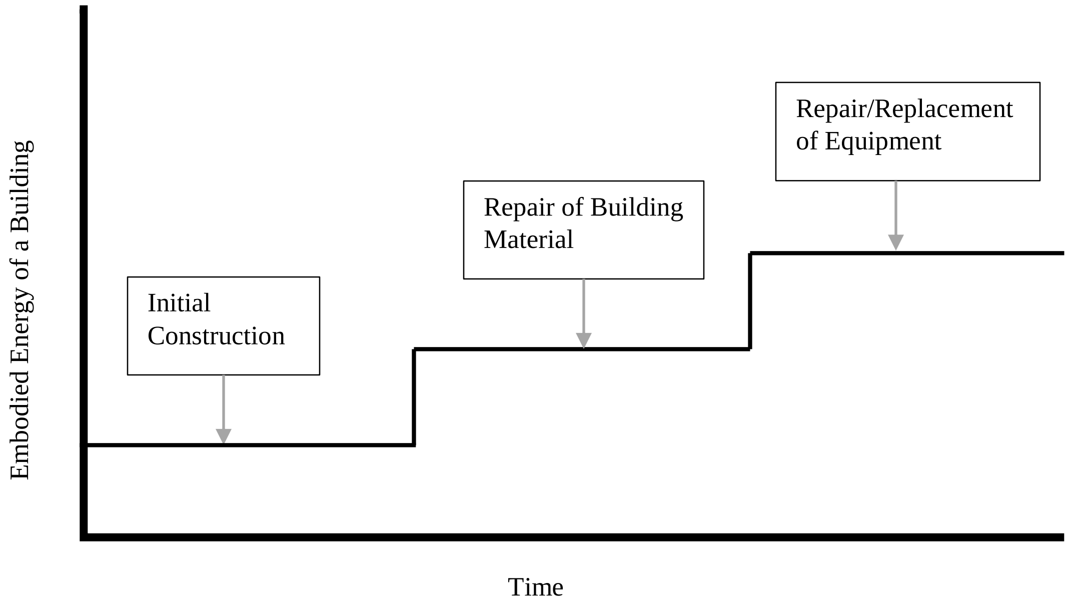



**Figure 4.6 Changes in Embodied Material with Regards to Repairs/Replacement**

Depending on the means of disposal of materials, the removed material could be subtracted from the total energy of the building (Liu 2009). The recycling of the material would reduce some of the energy of the original material due to losses in the recycling process, while the addition of repair materials would increase the total energy since more material is being added to the building. With the construction quality, the frequency of repairs needed would be changed due to the how fast the construction would fail to the decaying variables. The frequency of the repairs will be discussed during the review of the repair of materials curve later in the chapter.

The repair of equipment not only affects the changes to the embodied energy, but also the performance of the equipment for operational energy (Grussing and Liu 2013). The operational energy of the equipment, when repaired will be reduced since the efficiencies of the equipment could be increased due to the newer parts and repairs of systems. This operational energy decrease is also reduced with the material of the building when the infiltration and the thermal mass of the building is returned to a higher repair state. The repair of the material and equipment would need to be reviewed for the impact of the charges to the operational energy of the systems.

With repair the energy totals of a system dynamically change. The embodied energy of a repaired system will increase based upon what material is added. Conversely, the removal and disposal of material could partially reduce the embodied energy when recycled or reused. Reduction in embodied energy can only be for the energy saved from production of recycled materials compared to raw material production. The variable for increase of the embodied energy of a system is defined as:

$$\sum E_R = M_R' - R_{RM} \quad \textbf{(4.2)}$$

Where:

$E_R$ = Embodied Energy of the Repair Materials and Equipment, Combined

$M_R'$ = Embodied Energy of Added Material

$R_{RM}$ = Embodied Energy of Recycled Material

The embodied energy change of repairs can be predicted to some degree, based upon the maintenance schedules of equipment. With the regular maintenance, the additional material can be predicted, increasing the accuracy of the total building energy amount (Grussing and Marrano 2007).

With some the repairs to the system, the operational energy would also change. These repairs would need to be documented to model the change of performance of equipment (Yu 2013). To estimate the changes of regular maintenance repairs, a building would need to undergo the repair at least once to compare the changes made to the operational performance of the building. This is shown in the follow equation:

$$R_F = \frac{O_N}{O_P} \qquad \textbf{(4.3)}$$

Where:

$R_F$ = Repair factor

$O_N$ = New operational energy amount, for time, t

$O_P$ = Previous operational energy amount, for time, t

The repair factor must be measured by the change in operational performance over the same period of time in the year, to reduce extreme variations due to other factors such as the weather. This regular maintenance would be used to retune the performance curves of the system (M. N. Grussing 2013). Other, less frequent repairs would also be modeled in this form but not repeated on a schedule. Each change would need to be reviewed in this manner to assure proper accounting.

### 4.2.3 Replacement Schedule of Equipment

With the aging of building equipment, at a certain point it may be necessary for the equipment to be replaced. Each piece of equipment has a defined scheduled year of replacement by the manufacturer or by the standard practice of the industry (Hendron 2006). Even with this replacement schedule, the equipment might be changed before or after this date due to certain factors. The change of equipment could be accelerated or decelerated by remodel times, cost, occupancy changes, malfunction of equipment, and other factors (Ottoman, Nixon and Lofgren 1999). The building's embodied and operational energy will change with the new equipment. The newer equipment will define a new efficiency curve for the equipment with operational energy. The embodied energy is affected because of the new material and disposal of the old equipment. This causes a new change in the total energy of the building.

The material will change the total embodied energy of the system. This change is represented in the general formula by $M_R$, the remodeled embodied energy of materials and $E_R$, the embodied energy of equipment. The formula for the total energy accounting of remodeled material similar to the repair equation and is:

$$\sum ME_R = M' - R_M + E' - R_E \qquad \textbf{(4.4)}$$

Where:

$M_R$ = Embodied Energy of Materials and Equipment, Combined

$M^{'}$ = Embodied Energy of New Material

$R_M$ = Embodied Energy of Recycled Material

$E^{'}$ = Embodied Energy of New Equipment

$R_E$ = Embodied Energy of Recycled Equipment

The equation includes the recovered energy from recycling the materials/equipment. The recovered material's savings is based upon the saved energy from the difference of the energy used to renew the material versus brand new production. Each system analyzed for the remodel of materials is specific, with each dependent on the system and owner needs. With a specific system, there is variation if the remodel is regular enough to be predicted. For systems without regular remodels, the prediction system would be less accurate based on the system data.

The equipment replacement schedule within a system is more defined. Manufacturers specify estimated lifespans of equipment, or professional societies have general guidelines, to aid in replacement planning. With most building equipment built for long lifespans, each system would need to be reviewed individually to make accurate estimations. With the sum of these changes predicted, the model can be updated for the revised totals.

The replacement of materials and equipment must also be reviewed for the changes to operational energy. With any changes, the effect needs to be observed and compared to previous use to predict the energy changes (Yu 2013). This factor is used to 'reset' the degradation of the equipment efficiency and is calculated as:

$$R_F = \frac{O_N}{O_P} \qquad \textbf{(4.5)}$$

Where:

$R_F$ = Replacement factor

$O_N$ = New operational energy amount, for time, t

$O_P$ = Previous operational energy amount, for time, t

The review of the new and previous operational energy amounts need to be for the same time period each year, to negate the changes caused by other factors. The changes would become more accurate based upon the longer period of time used in the factor calculation.

### 4.3 – Secondary Building Factors

The secondary building factors are obtained from building data or location that are not primary to the degradation calculation process. These factors are used to normalize and modify the primary direct data for increased accuracy or for building comparisons. Also, the factors are used to compare different buildings for prediction analysis.  Each additional secondary factor can aid in the reliability of the final calculation models, but are not required for minimal or preliminary building work.

### 4.3.1 Age of Material/Equipment

The age of the material defines the remaining time until the end of life and needed replacement for the building equipment. Aging is a more subjective variable compared to others.  This is due to how the lifespan of a material changes based on the weather of the site, condition of the item, the frequency of repair, and the quality of the material.  Each of these issues can decrease or increase the lifespan of the material.  Even with the best of care, a material will achieve its end of life (Gupta 2006). The more worn out the material is the more infiltration is introduced to the building, raising the operational energy (Grussing and Liu 2013).  The material used for the repair of materials would also need to be considered for its age in relation to its lifespan to estimate the long term survivability of the repairs and the building’s performance as shown in the following figure.

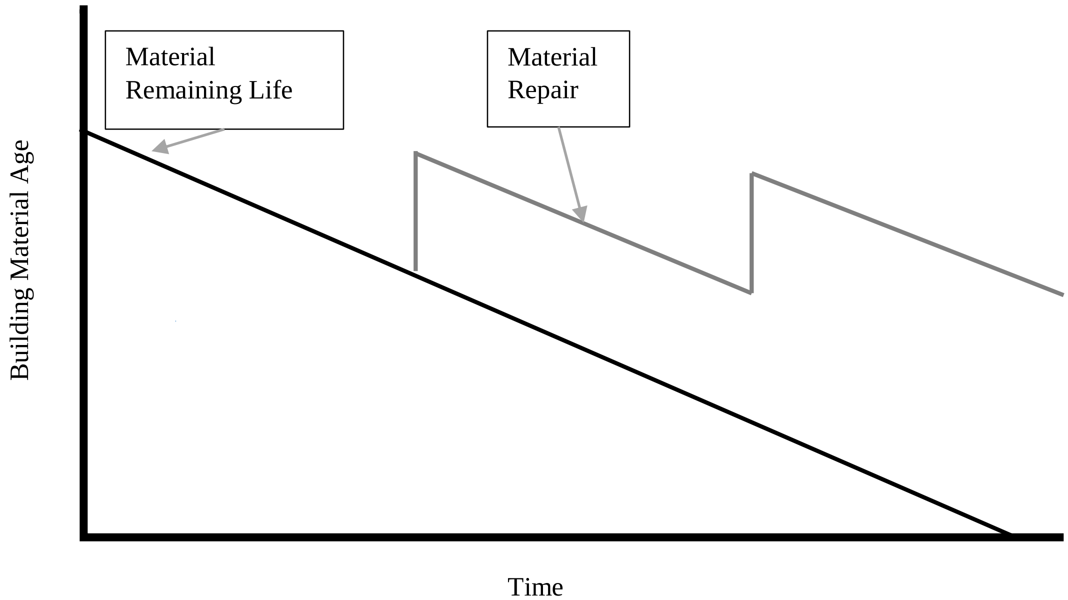



**Figure 4.7 Material Remaining Life** *(Grussing and Liu 2013)*

The aging of material is not completely based on the calendar age, but of the comparative age of the material based on the effects of the natural world versus 'standardized weathering.' This operation is important since the existing environment a material or piece of equipment is within will be different. For equipment there is a manufacturer baseline for the estimated operating lifespan, but based upon the maintenance, loading, operational hours, weather, and other conditions, the actual operating lifespan may be longer (Gupta 2006). The actual evaluated age is based upon inspection of the material/equipment. This age is not directly used within the general EDEC formula, but as a modifier to the other variables. This modifier better fits the equipment to the curves such as performance, increasing the reliability of the prediction model.

#### 4.3.2 Weather

The weather patterns of the building site changes how the building will behave over its' lifespan. The building, when designed well, will resist the infiltration of the climate as much as possible. When not well designed the climate will reduce the lifespan of materials, equipment, and performance of the building. Since the majority of all operational energy used in buildings is for comfort from HVAC and lighting, the weather is a large contributor to the total operational energy of the building. The yearly changes in weather will alter what type of energy and how much is used (Sailor and Vasireddy 2006). In the long term, the climatic trends predicted will be needed to review the energy loads on the building, modifying the energy used each year. The predicted climatic changes can also aid in reviewing the lifespan of equipment and materials and organizing a long term repair schedule to reduce waste (Yalcintas 2008).

The weather variable is based upon the climatic changes that are being tracked, as well as the climate of the area. Regional climates will be used to compare variables such as rainfall, temperature minimums and maximums, severity of weather, sun exposure, wind variable, and other minor changes (Sailor and Vasireddy 2006). The regional climates will be used to contrast the decay of buildings/equipment indifferent locations. The material quality can be compared by multiple regions to aid in review of how climate affects the damage of material in long term systems. The regional climates will also be used to review the HVAC performance within different regions.

With the equipment performance curve, the effect of efficiency degradation can be observed in real world models. This change indicator of performance compared to efficiency could be reviewed for local weather cycles, giving a more dynamic look at the possible changes to the system over time (Yalcintas 2008). This also aids in the comparison and contrast of multiple sites in different climates. A contrast of buildings with similar systems will aid in review of what design methodologies work within which climate zones. The standardization of the performance load is:

HVAC Energy Change Per Temperature Unit

$$P_{HVAC\ adj.} = \frac{\Delta P_{HVAC}}{\Delta T} \quad \textbf{(4.6)}$$

Where:

$P_{HVAC}$ = Power consumed by HVAC Equipment

$\Delta P_{HVAC}$ = Energy change by month, per year

$\Delta T$ = Change in Temperature by month, per year

The weather data for a location will be evaluated on a per month basis. Each month's evaluation will include the average maximum temperature, the average mean temperature, and the average minimum temperature over the years where operational data is provided. A comparison of the yearly change to monthly averages will also be used to track building energy use. An example is provided on Table 4.1 and Table 4.2.

**Table 4.1 Median Temperature, Lawrence, KS, Fahrenheit**

| Year | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003 | 26.9 | 31.5 | 44.2 | 58.3 | 65.3 | 71.8 | 82.3 | 81.7 | 66.6 | 60.5 | 45.4 | 33.4 |
| 2004 | 28.6 | 30.6 | 48.3 | 56.4 | 67.1 | 72.5 | 76.2 | 73.7 | 71.1 | 57.6 | 45.6 | NR |
| 2005 | 28.8 | 38.1 | 43.6 | 56.6 | 64.4 | 75.7 | 78.3 | 77.3 | 71.9 | 57.5 | NR | 22.8 |
| 2006 | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR |
| 2007 | NR | NR | NR | NR | 68.6 | 73.7 | 78.5 | 83.5 | 70.3 | 58.8 | 42.8 | 28.3 |
| 2008 | 26.4 | 28 | 40.3 | 49.7 | 62 | 74.2 | 77.7 | 74.6 | 66.2 | 54.5 | 43.3 | 28.2 |
| 2009 | 28.6 | 38.5 | 43.3 | 52.3 | 64.5 | 75.2 | 74.1 | 73.5 | 65 | 49.7 | 49.1 | 27.6 |
| 2010 | 22.7 | 27 | 43.5 | 60.1 | 63.1 | 77.1 | 79.7 | 80.4 | 70.2 | 59.7 | 45.4 | 31.2 |
| 2011 | 24.4 | 29.2 | 43.7 | 57.2 | 64 | 76.4 | 85 | 80.8 | 66.8 | 59.2 | 46.4 | 38 |
| 2012 | 36.7 | 38.9 | 59.7 | 62.2 | 71.9 | 78.3 | 86.4 | 78 | 70.5 | 56.4 | 49.2 | 37.3 |
| 2013 | 34.1 | 35.3 | 38 | 50.6 | 64.6 | 74.5 | 77.4 | 76.3 | | | | |

**Table 4.2 Difference in Median Temperature by month, per year for Lawrence, KS, Fahrenheit**

| Year | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003-2004 | 1.7 | -0.9 | 4.1 | -1.9 | 1.8 | 0.7 | -6.1 | -8 | 4.5 | -2.9 | 0.2 | N/A |
| 2004-2005 | 0.2 | 7.5 | -4.7 | 0.2 | -2.7 | 3.2 | 2.1 | 3.6 | 0.8 | -0.1 | N/A | N/A |
| 2005-2006 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2006-2007 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2007-2008 | N/A | N/A | N/A | N/A | -6.6 | 0.5 | -0.8 | -8.9 | -4.1 | -4.3 | 0.5 | -0.1 |
| 2008-2009 | 2.2 | 10.5 | 3 | 2.6 | 2.5 | 1 | -3.6 | -1.1 | -1.2 | -4.8 | 5.8 | -0.6 |
| 2009-2010 | -5.9 | -11.5 | 0.2 | 7.8 | -1.4 | 1.9 | 5.6 | 6.9 | 5.2 | 10 | -3.7 | 3.6 |
| 2010-2011 | 1.7 | 2.2 | 0.2 | -2.9 | 0.9 | -0.7 | 5.3 | 0.4 | -3.4 | -0.5 | 1 | 6.8 |
| 2011-2012 | 12.3 | 9.7 | 16 | 5 | 7.9 | 1.9 | 1.4 | -2.8 | 3.7 | -2.8 | 2.8 | -0.7 |
| 2012-2013 | -2.6 | -3.6 | -21.7 | -11.6 | -7.3 | -3.8 | -9 | -1.7 | | | | |

### 4.3.3 Material Quality

The quality of the material used in the building and equipment will change the total lifespan of the building. A material's lifespan is dependent on the quality of the material. With caulking, for example, a lower quality caulk will deteriorate from age and the elements at a higher rate, therefore the caulk will wear out, leaving an opening in the building envelope (Taylor, Counsell and Gill 2013). This opening, will let in water and air, increasing damage to the building from the weather. The damage will need to be repaired, affecting the embodied energy of the building. The opening also will make the HVAC system load higher, thereby increasing the operational energy used for that period of time (Taylor, Counsell and Gill 2013). The quality of materials is chosen by the owner and designer. If the owner and designer are choosing with value engineering in mind, the lifespan of the building is lower, therefore increasing the speed of decay of the building. The decay of building materials is shown in Figure 4.8.

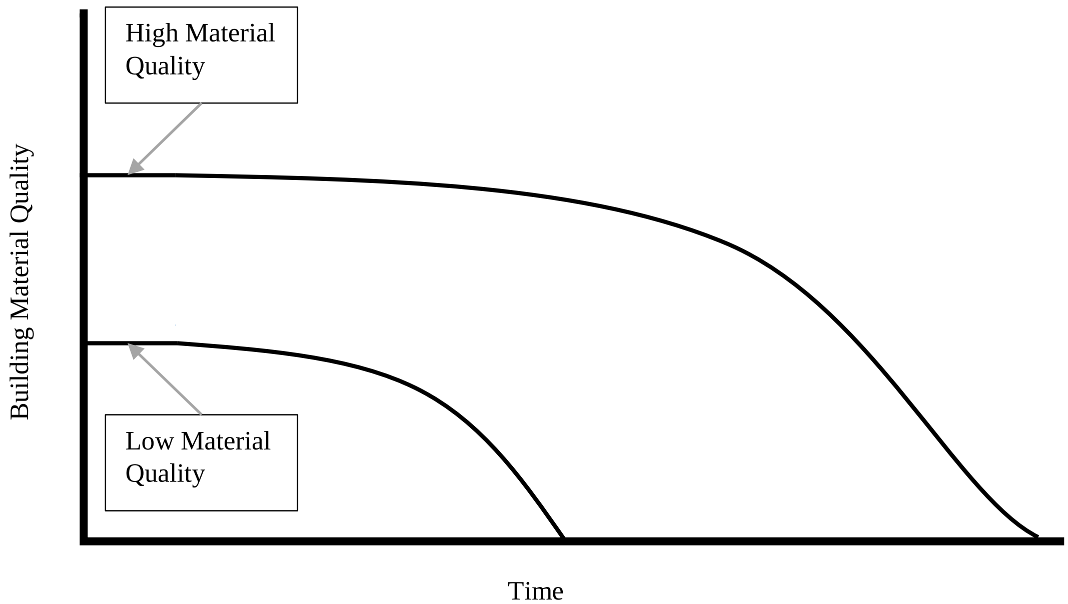



**Figure 4.8 Building Material Quality Vs. Time** *(Taylor, Counsell and Gill 2013)*

The quality of the building materials is also dependent on other variables of EDEC. The climate of the area affects how a material reacts and ages. A high quality wood might be used in a project located in a humid area and, the material could rot quickly if the wood is not suitable for that climate. This means the material quality is dependent on both the direct quality of the material and the indirect result of the weather. These important modifiers for material quality are intertwined leading to varying degrees of reliability dependent on current research areas. To fully understand the relationship, larger-scale research is needed that is not included within this scope of research.

## 4.4 Comparative Factors

Comparative factors are current factors whose only use is for building comparison. This comparison will be used to gather more data for the prediction models. This creates a more accurate factor for complex systems which can have many variables that are difficult to analyze for their total impact, or are transient in nature.

### 4.4.1 Construction Quality

One of the most defining systems for the performance of buildings is the initial construction quality (ASHRAE 2009). The construction of the building establishes how close the building is to the material failure point at the start of life. If the building has poor construction, the maintenance schedule needed to support the building is increased from the onset, therefore using more materials to repair and increasing the embodied energy.

Poor construction quality would also affect the operational energy of the building. The infiltration of outside weather is higher with poor construction, increasing the operational load of the building's systems (Taylor, Counsell and Gill 2013). In addition the quality of the equipment used in the building is reduced, which also increases the operational energy needed to run the building as illustrated is Figure 4.9.

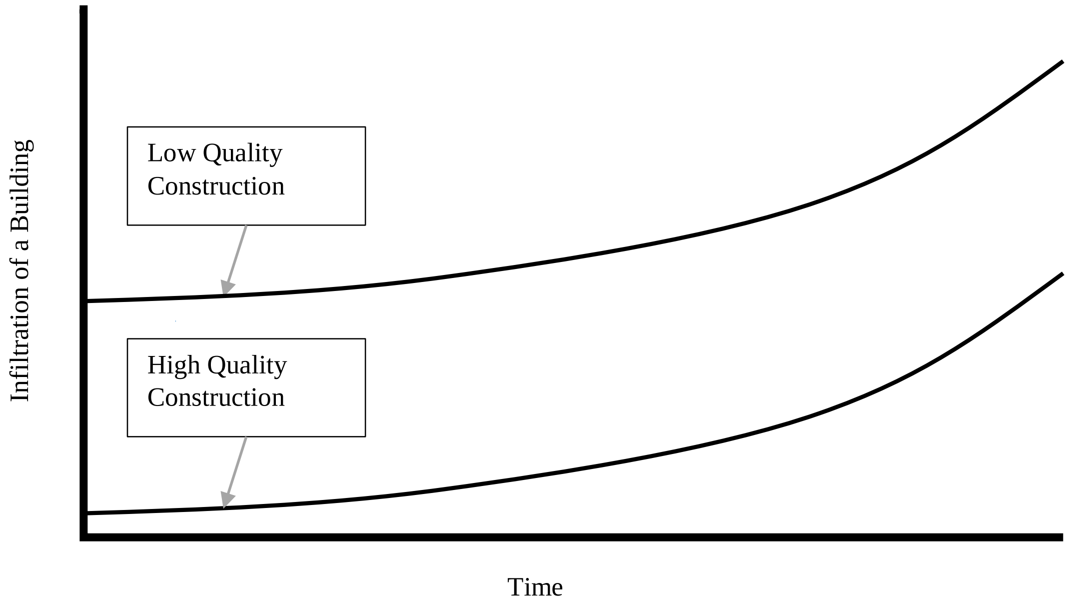



**Figure 4.9 Infiltration of a Building of Various Construction Quality**

The research on the effect of construction quality and how it relates to operational efficiency has been done, leading to current methods of estimation about the performance of HVAC systems.

The quality of the construction of a system is used as a comparison of buildings and their data. A lower construction quality building will behave differently than a high construction quality, therefore a comparison of the building's operational energy is needed. A direct comparison can be calculated as follows:

$$CQ_F = \frac{\frac{P_{B1}}{A_1}}{\frac{P_{B2}}{A_2}} \quad \textbf{(4.7)}$$

Where:

$CQ_F$ = Construction Quality Comparison Factor

$P_{B1}$ = Power consumption of Building 1

$P_{B2}$ = Power consumption of Building 2

$A_1$ = Area of Building 1

$A_2$ = Area of Building 2

This system will only work within the comparison of two buildings with all other variables accounted for.

### 4.4.2 Occupancy Use

The occupancy of a space defines the operating schedule of equipment. For example an office building, the main equipment operating hours are during a standard work week, while a retail shop will have longer operating hours each day. The occupancy of the building therefore changes the operational energy (Menezes, et al. 2012). If the occupancy is changed, the energy use would change as well. Predicting the changes in occupancy is more difficult since it is not known what the new tenant of a space will be and what equipment is needed. The occupant load could also change erratically based on many different factors that are outside the scope of this research. This pattern, however, is also present in the operational energy used in the system. This allows us to account for the energy use of the occupants.

Another issue with this variable is if the building undergoes a change of use. With a change of use, the building would have different needs than before, changing the operational energy of the system (Menezes, et al. 2012). This change would be predicted in the same manner as with the changes to operational energy of equipment replacement, monitoring the percent change of the energy used over the same time period. This is present in equation 4.12.

$$O_F = \frac{O_N}{O_P} \qquad \textbf{(4.8)}$$

Where:

$O_F$ = Occupancy change factor

$O_N$ = New operational energy amount, for time, t

$O_P$ = Previous operational energy amount, for time, t

This change is less predictable, making the use of this variable less ideal. This change would need building specific data and timelines to show if there is any noticeable effect.

## 4.5 Degradation of Equipment Formula

The long term degradation of equipment efficiency is key to EDEC. The degradation curve for efficiency is complex due to complex systems of equipment designs. A baseline review of HVAC split equipment was conducted by the National Renewable Energy Laboratory (NREL). The basic formula is provided (Hendron 2006):

$$SEER = SEER_{Base} * (1 - M)^A \qquad \textbf{(4.9)}$$

Where:

SEER = Seasonal Energy Efficiency Ratio

$SEER_{Base}$ = Baseline Seasonal Energy Efficiency Ratio

M = Maintenance Factor

A = Age, years

The SEER rating is based upon the output energy divided by the input energy, as shown in equation 4.14.

$$SEER = \frac{\frac{Btu}{hr}}{kWh} \qquad \textbf{(4.10)}$$

A modification of equation 4.13 for use with input HVAV energy is:

$$\frac{Output}{input_{modified}} = \frac{Output}{Input} * (1 - M)^{Age}$$

$$\frac{Input}{Input_{modified}} = (1 - M)^{Age}$$

$$Input_{modified} = \frac{Input}{(1 - M)^{Age}}$$

Therefore:

$$E_{Mt} = \frac{E_b}{\left(1 - M_f\right)^t} \qquad \textbf{(4.11)}$$

Where:

$E_{Mt}$ = Energy modified for degradation, kWh/yr

$E_b$ = Energy baseline for initial equipment year, kWh/yr

$M_f$ = Modification factor

t = time from initial equipment year

With an HVAC system that has many design options compared to split systems, a degradation formula is more complex to derive. The basic HVAC degradation usage will have the modifier be the actual degradation compared to baseline methods researched by NREL (Hendron 2006). With the factor based upon maintenance, the air handling unit, chillers, and cooling tower would be on one factor; while the boiler would be set on a different maintenance factor.

**4.6 General EDEC Formulas**

To model EDEC curves, the variables discussed must be mathematically modeled. The modeling has to account for the combination of embodied and operational energy. The modeling would be done in three sections; baseline accounting, yearly accounting; and prediction accounting. The baseline accounting is the total energy of the construction of the building, from the material to the construction operational energy. This baseline is to be accounted to avoid being influenced by the prediction models. The yearly accounting is for the occupancy lifespan of the building. This operational period would need to account for all energies expended from the use of the building. The energy comes from operational sources such as HVAC, lighting, and other machinery with the embodied energy coming from repairs, remodels, and replacement of equipment. The variables for prediction are based on the operational lifespan data. This prediction accounting would use modifiers to calculate the long-term changes to the yearly lifespan energy model. The first two parts of the total energy calculation are from gathering the direct building data, while the third phase incorporates variables derived from the building and other disciplines. The modeling of the prediction requires new methods and formulas to be investigated for accuracy of the model. The interconnection of this process is provided in Equation 4.1.

EDEC Formula (General):

$$\sum EDEC = (M_i + ME_r) + (E_I + E_R) - (R_m + R_e) + \sum E_{Mt} \qquad \textbf{(4.12)}$$

$M_i$ = Energy from construction Material, initial

$ME_R$ = Energy from construction Material and Equipment, remodel

$E_i$ = Energy from equipment embodied, initial

$E_R$ = Embodied energy of repairs

$R_m$ = Recovered Energy, materials

$R_e$ = Recovered Energy, equipment

$E_{Mt}$ = Energy modified for degradation, kWh/yr

This equation provides the fundamental relationship of the construction, operational lifespan and modifying factors of the prediction variables. These formulas take the original embodied energy and the additional remodel, repair or replacement embodied energy as set sums. This is because the embodied energy is added when material or equipment is added since materials after being made/installed would not have their energy change. The only way to recoup embodied energy is to recycle or reuse material, saving energy from the raw material production cycle. The addition of embodied materials could be predicted and added to the EDEC model.

### 4.7 Sources of Variable Data

To review each of these variables for their EDEC criteria, sources of data need to be chosen. Due to the breath of the information required, many disciplines will need to be unified to accurately model decay and degradation of a building. With EDEC proposing a new method of total building energy accounting, early verification of the predictive simulations need to use current available data. These preliminary data sources for variable curves were discussed in Chapter 3. The data sources chosen for the EDEC analysis were from the Commercial Building Energy Consumption Survey compiled from the Energy Information Agency, an Embodied and Operational Energy Review of KDOT Campuses, building material data from $M^2$SEC construction, ICE Version 2.0 embodied energy for building materials, and operational energy data from Eaton Hall based in the University of Kansas Campus. The breakdown or how each source of data will be utilized for each variable curve is displayed in Figure 4.10.

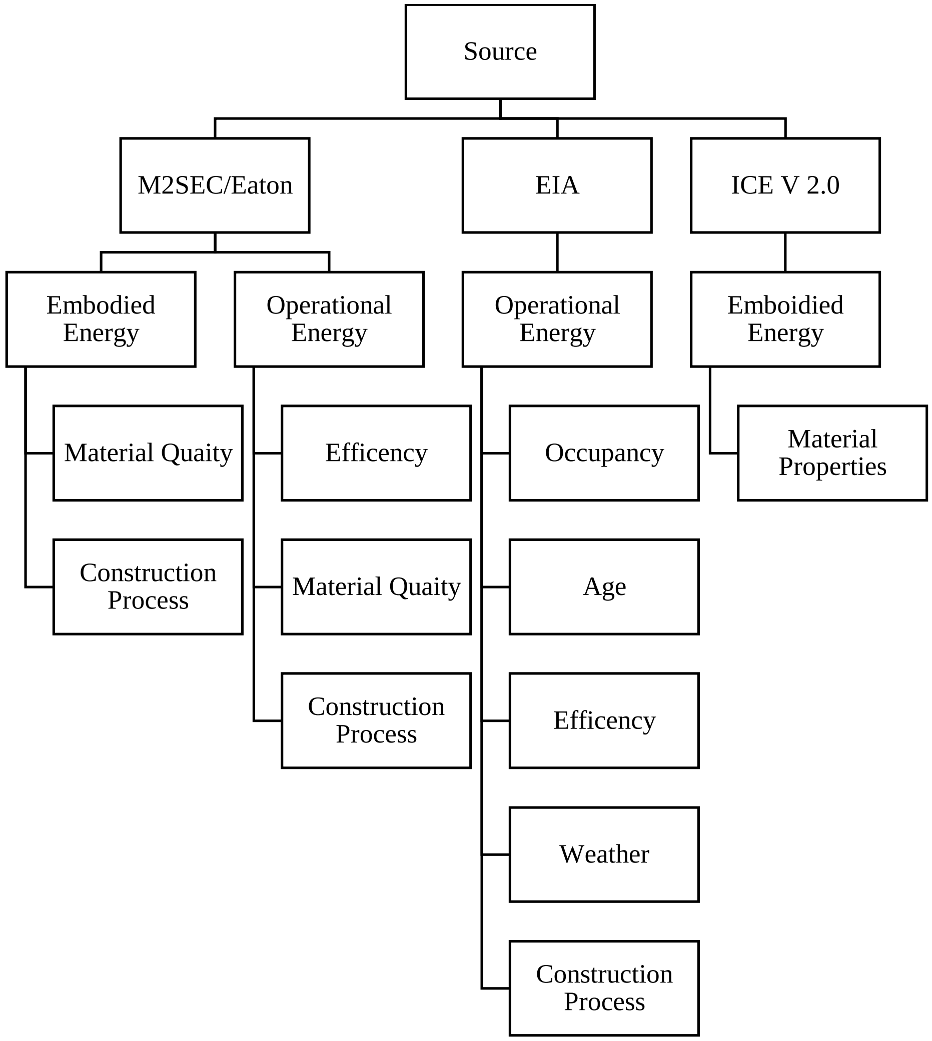
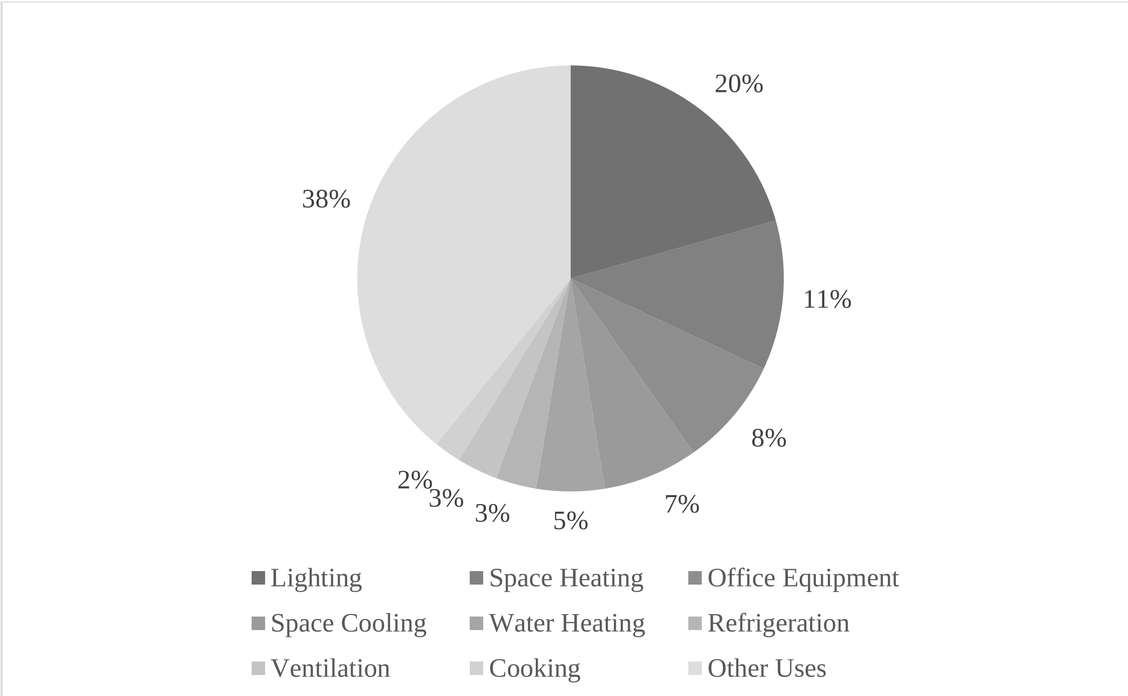


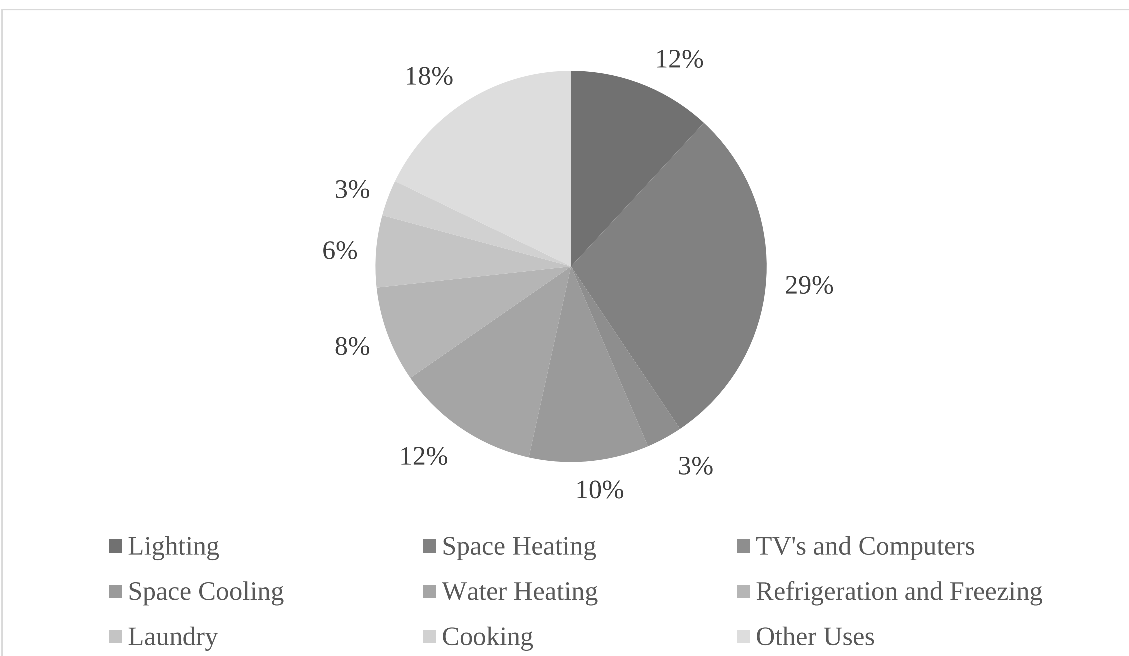

**Figure 4.10 Data Source and Use Tree**

The EIA, ICE Version 2.0, and KDOT data will be used to develop the variable curves to compare to the simulations of operation energy use of Eaton and total building prediction of M$^2$SEC. M$^2$SEC's materials data will be used to provide the baseline building energy totals, with the prediction models calculated for the building to estimate lifetime energy accounting. Therefore three case studies will be done, one on operational energy with early lifespan predictions, embodied energy prediction with mid lifespan predictions, and one long term total building prediction.   The total breakdown of a commercial and residential building's operational energy use is shown in Figure 4.11 and Figure 4.12.




Other uses include telecommunications, medical equipment, pumps, generators, combined heat and power systems, manufacturing and other miscellaneous uses.

**Figure 4.11 Energy Use in U.S. Commercial Buildings**




Other uses include pool equipment, furnace fans, dishwashers, and other miscellaneous uses.

**Figure 4.12 Energy Use in U.S. Residential Buildings**

As most of the energy defined by long term equipment, such as HVAC (21% of commercial buildings and 39% residential buildings), water heating (5% commercial, 12% residential), and cooking equipment (2% commercial, 3% residential); maintaining the optimum efficiency is advantageous to reducing long term operational energy changes (U. S. Energy Information Administration 2003).

### 4.8 Utilization of EDEC

With the data sources and the variables chosen, the appropriate variable curves need to be reviewed for their total effect on the building's lifespan accounting. With the provided data, some variables of degradation could greatly increase energy totals, while other variables may be negligible. In other situations, such as occupancy, prediction of changes may not be viable for accurate calculations. To review the impact of each curve, an analysis of each variable and the creation individual formulas is accomplished. With the variable formulas completed, a proper EDEC prediction curve can be modeled and compared to observational data.

## Chapter 5  EDEC Analysis Case Studies

### 5.1 Case Study 1

The first case study is to review the degradation of operational energy within a building.  The building selected for this analysis is Eaton Hall at the University of Kansas in Lawrence.  Eaton hall was opened in October of 2003, for the School of Engineering. The building houses classrooms and offices with the school's computer labs, and the electrical engineering and computer science laboratories.   This building is three stories with a mechanical basement.  The building is shown below:

**Figure 5.1 Eaton Hall**

Eaton hall is 80,000 square feet of floor space, and is open twenty-four hours a day, every day of the year. This constant opening will greatly affect how much energy the building uses. The site is in a temperate zone which has large temperature changes throughout the year. The average monthly temperature is show in Table 5.1.

**Table 5.1 Median Temperature, Lawrence, Fahrenheit**

| Year | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003 | 26.9 | 31.5 | 44.2 | 58.3 | 65.3 | 71.8 | 82.3 | 81.7 | 66.6 | 60.5 | 45.4 | 33.4 |
| 2004 | 28.6 | 30.6 | 48.3 | 56.4 | 67.1 | 72.5 | 76.2 | 73.7 | 71.1 | 57.6 | 45.6 | NR |
| 2005 | 28.8 | 38.1 | 43.6 | 56.6 | 64.4 | 75.7 | 78.3 | 77.3 | 71.9 | 57.5 | NR | 22.8 |
| 2006 | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR |
| 2007 | NR | NR | NR | NR | 68.6 | 73.7 | 78.5 | 83.5 | 70.3 | 58.8 | 42.8 | 28.3 |
| 2008 | 26.4 | 28 | 40.3 | 49.7 | 62 | 74.2 | 77.7 | 74.6 | 66.2 | 54.5 | 43.3 | 28.2 |
| 2009 | 28.6 | 38.5 | 43.3 | 52.3 | 64.5 | 75.2 | 74.1 | 73.5 | 65 | 49.7 | 49.1 | 27.6 |
| 2010 | 22.7 | 27 | 43.5 | 60.1 | 63.1 | 77.1 | 79.7 | 80.4 | 70.2 | 59.7 | 45.4 | 31.2 |
| 2011 | 24.4 | 29.2 | 43.7 | 57.2 | 64 | 76.4 | 85 | 80.8 | 66.8 | 59.2 | 46.4 | 38 |
| 2012 | 36.7 | 38.9 | 59.7 | 62.2 | 71.9 | 78.3 | 86.4 | 78 | 70.5 | 56.4 | 49.2 | 37.3 |
| 2013 | 34.1 | 35.3 | 38 | 50.6 | 64.6 | 74.5 | 77.4 | 76.3 | | | | |

### 5.1.1 Sources of Operational Energy Use

The operational energy of Eaton Hall must be reviewed for the source of the energy use. The electricity use of the building would vary based upon what equipment is being used at that time. The occupancy of Eaton hall changes drastically around the University class schedules. The fall semester runs from the middle of August to early December, with the spring semester running from Mid-January to Mid-May, and The Summer semester is during late June through July. This means the building energy use from the direct interaction of the occupants is reduced during January, May, June, August, and December when classes are not in session. With the HVAC system within the building, the electricity used for cooling is absent within certain months when the weather makes the need for cooling redundant, while the district steam is used for heating of the building.

The three main building energy variables need to be separated from the general utility data. The data is separated and used per the following figure:

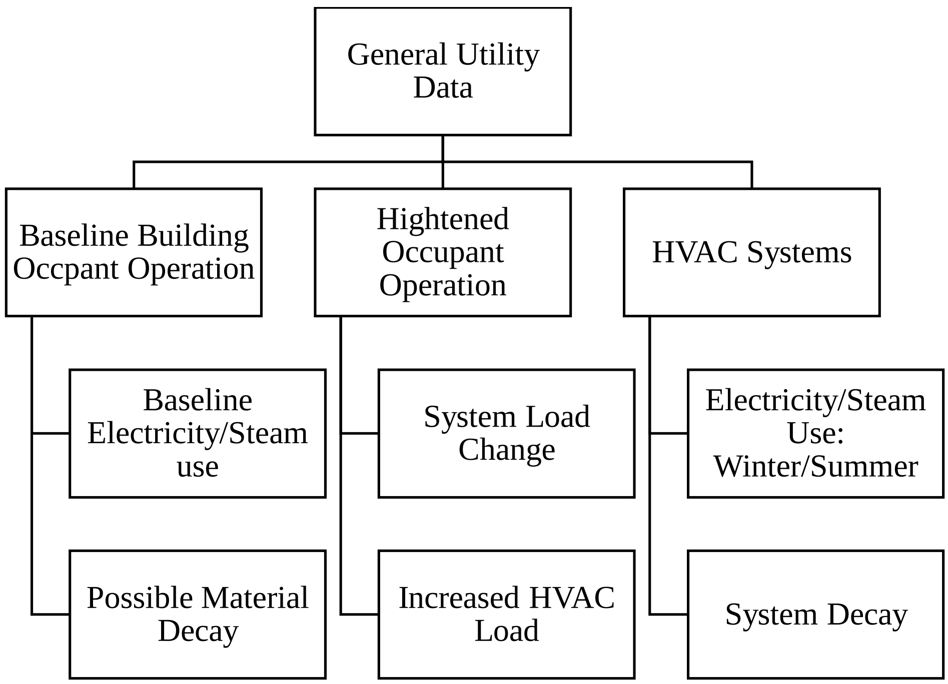



**Figure 5.2 Relationship of Utility Data and EDEC Variables**

It is required that the source of the energy use is separated to accurately apply the decay methods. To separate the building energy utilizations, the needed data is hard to record at this time, due to how there most buildings do not have building equipment monitored for energy tracking, increasing the difficulty of the analysis. Eaton Hall is included within these buildings, so building use will need to be reviewed based on known dynamic changes to the systems. The building's energy used from 2003 to 2012 is graphically shown in the next two figures:

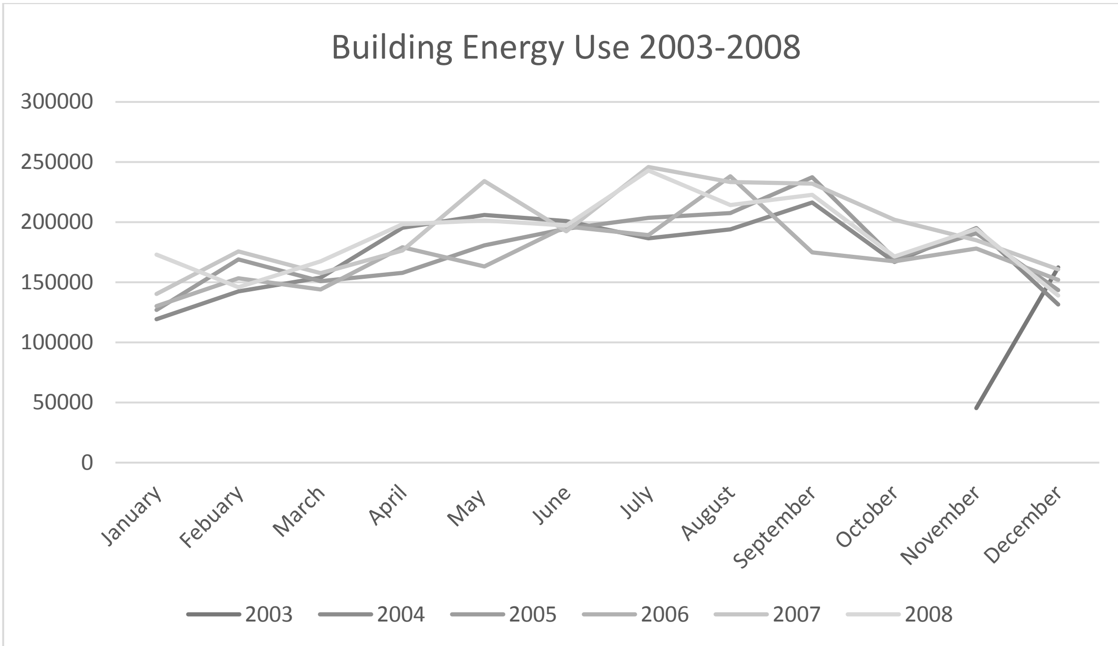



**Figure 5.3 Building Energy Use 2003-2008**

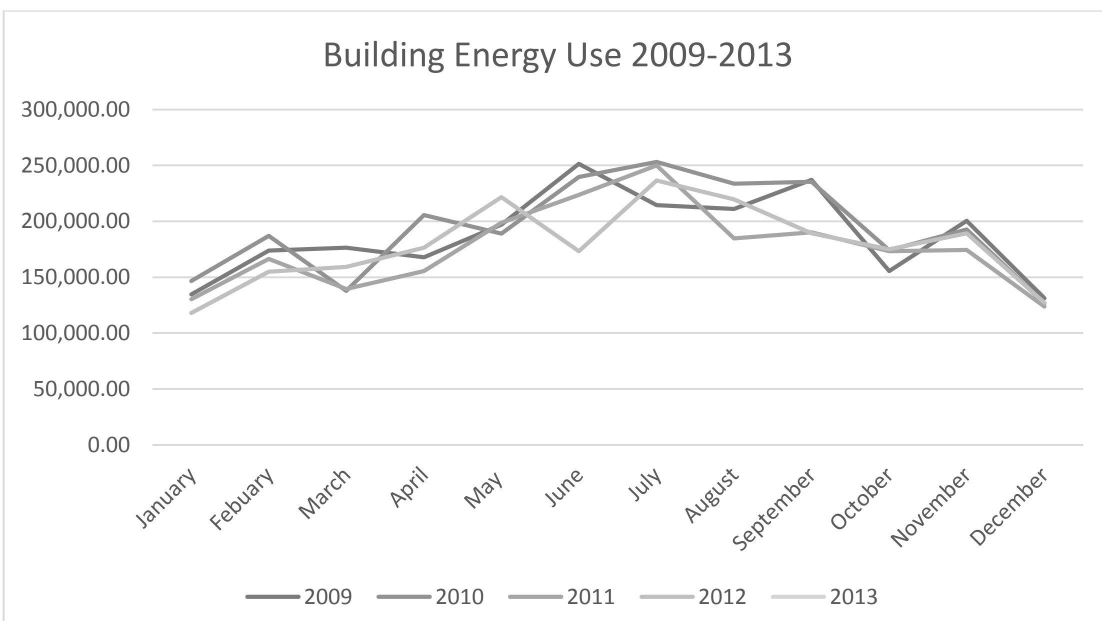



**Figure 5.4 Building Energy Use 2009-2013**

The building's energy use follows certain trends that can be derived from the dynamic trends within the building. Therefore, each of the three building energy uses can be defined for EDEC use. These basic trend can be viewed with the average monthly building energy use as shown in Figure 5.5.

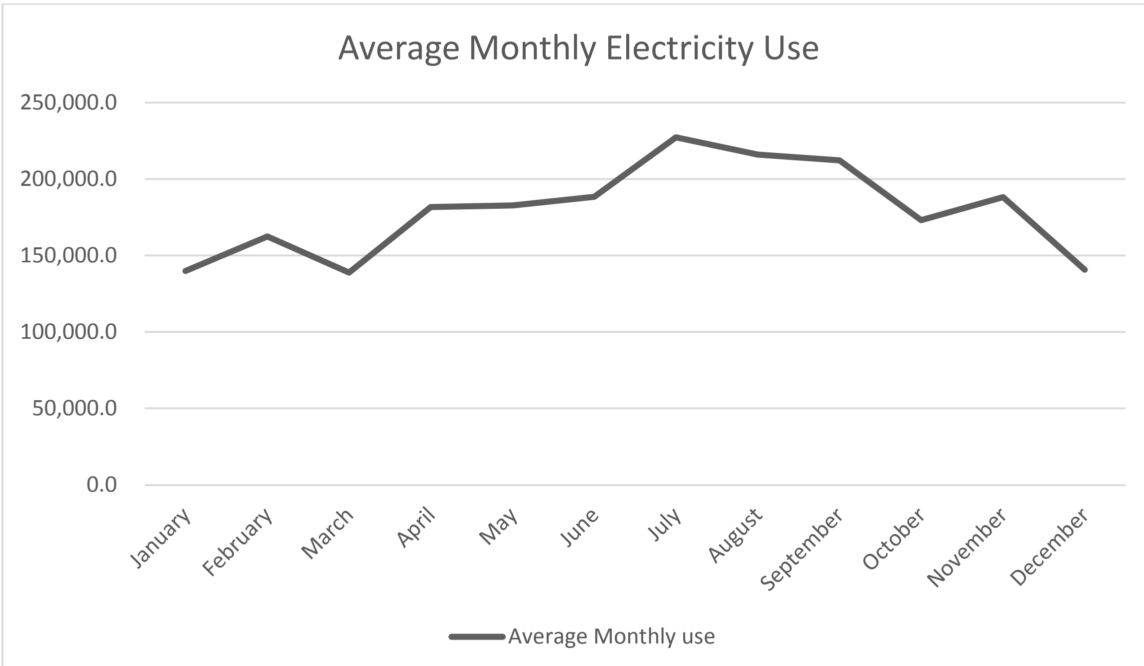



**Figure 5.5 Eaton Hall Average Monthly Electricity Use**

### 5.1.2 Separating Operational Energy Uses

The building electricity energy use shows how dynamic each month is for the building needs. The January, February, and December months would not need HVAC cooling as shown by the median average monthly weather data as shown in Table 5.1. The outside cool air would be used for air cooling, saving building energy, while the district steam would be used at this time for HVAC heating, which will be discussed later in this chapter. For occupancy changes, February, April, September and November, are the months of the classes schedule that are in session for the full month, defining the highest occupant energy use. March, May, August, and October have some part of the month without classes that would skew the results. The highest use of HVAC cooling chillers would be during June, July and August, as shown in the weather table. Therefore the viable months used to find each building energy value is show in Figure 5.6.

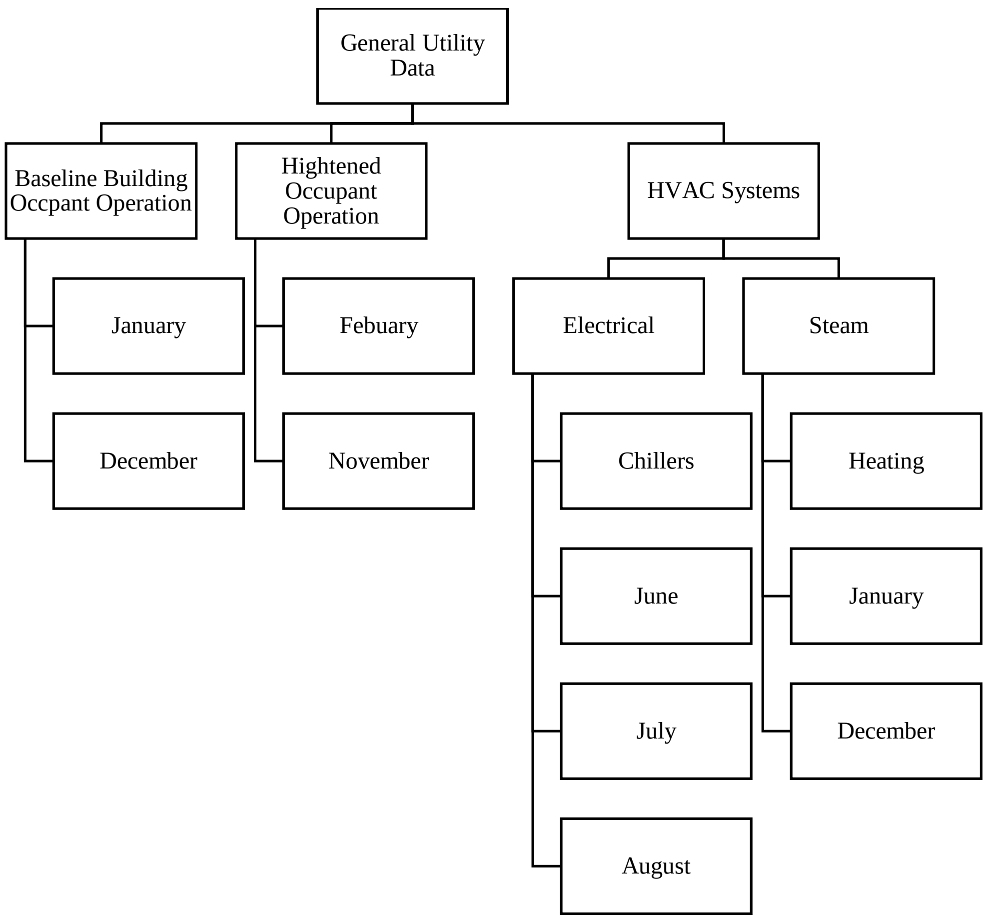



**Figure 5.6 Viable Months for System Analysis**

The baseline occupant energy use will then be reviewed on the average energy monthly energy use for January and December since the class schedule is shorter and very little cooling would be used, making the review baseline occupant use possible. This occupant use would have most of the computers in the labs on, and academic research projects would continue even when classes are not in session. This research and its energy use can change from year to year, thus an average would be needed to remove some variables. The monthly energy use for January and December of each year is shown in Table 5.2.

**Table 5.2 Monthly Energy Use for January and December, kWh**

| Year | January | December |
|---|---|---|
| **2003** | | 162260 |
| **2004** | 119190 | 131510 |
| **2005** | 127070 | 143420 |
| **2006** | 130050 | 151930 |
| **2007** | 140370 | 160720 |
| **2008** | 172950 | 138960 |
| **2009** | 134630 | 131240 |
| **2010** | 146710 | 126550 |
| **2011** | 130340 | 123700 |
| **2012** | 118050 | 127163 |
| **2013** | 167030 | 162260 |

The average baseline occupant energy used per month based upon these values is

$$E_{BA} = 140{,}292\ kWh$$

This baseline energy use will be removed from all months to find the highest occupant energy use and HVAC use for the rest of the building. Since EDEC focuses mainly on the building and large scale equipment, the occupant energy would be removed to show the changes in HVAC use per month.

The occupant levels in the building change from the course schedule. For the University of Kansas, School of Engineering, the influx of students is during the spring and fall semesters. This increased load would need to be accounted for to properly review the degradation curves.  The number of days where classes are in session per month, including weekends is provided below:

**Table 5.3 Class Occupancy Days Vs. Days of Month**

| Month | Number of Class Days | Total Number of Days | Percent |
|---|---|---|---|
| **January** | 18 | 31 | 58.1% |
| **February** | 28 | 28 | 100% |
| **March** | 22 | 31 | 77.4% |
| **April** | 30 | 30 | 100% |
| **May** | 15 | 31 | 48.4% |
| **June** | 0 | 30 | 0.0% |
| **July** | 0 | 31 | 0.0% |
| **August** | 6 | 31 | 19.35% |
| **September** | 30 | 30 | 100% |
| **October** | 27 | 31 | 87.1% |
| **November** | 26 | 30 | 86.7% |
| **December** | 19 | 31 | 61.3% |

While a fully accurate model of occupant load cannot be determined since the information was not recorded, a model of occupant load changes can be determined by providing the energy used versus the number of class days to estimate the average number of kWh used per day, baseline and the increased load per day.  The estimation is calculated using Equation 5.1:

$$E_{MA} = E_b * T_m + E_i * T_c \qquad \textbf{(5.1)}$$

Where:

$E_{MA}$ = Average monthly energy used, kWh

$E_b$ = average baseline energy use, per day, kWh

$E_i$ = Average increased daily energy use, kWh

$T_m$ = Number of days in the month

$T_c$ = Number of days of month with classes

Comparing the Monthly energy averages for January and December, the baseline daily energy and occupant energy increase are as follows:

January:

$$E_{MA\ Jan} = E_b * T_{m\ Jan} + E_i * T_{c\ Jan}$$

$$139924\ kWh = E_b * 31 + E_i * 18$$

$$139924 - E_i * 18 = E_b * 31$$

$$\frac{139924 - E_i * 18}{31} = E_b$$

December:

$$E_{MA\ Dec} = E_b * T_{m\ Dec} + E_i * T_{c\ Dec}$$

$$140660\ kWh = E_b * 31 + E_i * 19$$

$$140660 - E_i * 19 = E_b * 31$$

$$\frac{140660 - E_i * 19}{31} = E_b$$

Solving for $E_i$:

$$\frac{139924 - E_i * 18}{31} = \frac{140660 - E_i * 19}{31}$$

$$139924 - E_i * 18 = 140660 - E_i * 19$$

$$E_i = 736\ kWh/d$$

Soving for $E_b$:

$$139924\ kWh = E_b * 31 + 736 * 18$$

$$139924 = E_b * 31 + 13248$$

$$\frac{126676}{31} = E_b$$

$$E_b = 4086\ kWh/d$$

Therefore the baseline energy use for Eaton Hall for occupants is 4086 kWh per day with 736 kWh per day increase when classes are in session. With this calculated an energy use curve for the HVAC system can be estimated.

### 5.1.3 HVAC Steam Energy Use

The data provided for the district steam that is used will also need to be reviewed for the grouping of energy uses. For steam usage, the data is inconsistent, as shown in Figure 5.7.

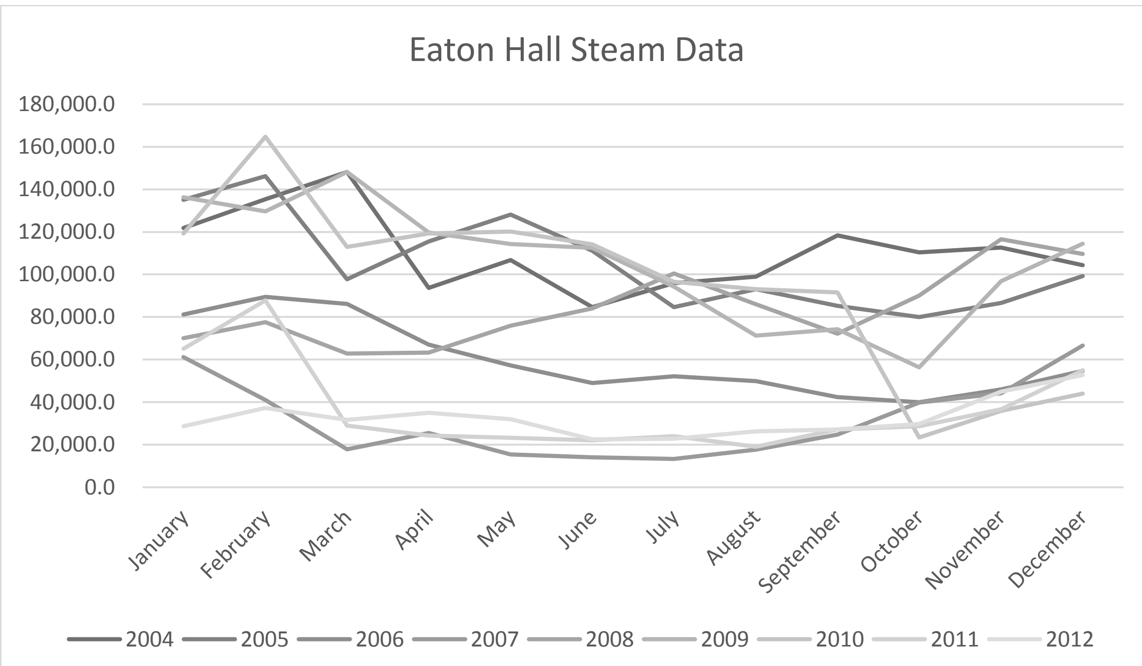



**Figure 5.7 Eaton Hall Steam Usage**

The steam usage from the HVAC use would trail off during months with a higher temperature. The month’s data do not show this general trend for each year. One year’s weather can be cooler than another, while the steam energy use is four times greater. This irregular data could be caused by changes in how the data is monitored, such as switching from grouping buildings on one meter to separate meters or increased use for other systems.  For a conservative estimate, the last two full years of steam data will be the basis for energy use.  The average baseline yearly steam energy use is 22,700 gal/mo. from the summer months, when the heating for the HVAC is minimal.  To convert the gal/mo to kWh, a conversion is needed where:

$$E_s * \frac{1}{\frac{0.13368\frac{ft^3}{gal}}{Specfic\,Vol.}} * \frac{\frac{btu}{lb}}{\frac{kWh}{btu}} = E_{sc} \quad \textbf{(5.2)}$$

$$E_{sc} = 1_{gal} * \frac{1}{\frac{0.13368\ \frac{ft^3}{gal}}{2.74\frac{ft^3}{lb}}} * \frac{1194\frac{btu}{lb}}{3412\frac{kWh}{btu}} = 7.17\ kWh/gal$$

The total and heating monthly average energy use converted to kWh is shown in Table 5.4.

**Table 5.4 Monthly Average Steam Energy Use**

| MONTH | AVERAGE ENERGY USED, GAL | AVERAGE ENERGY USED, KWH | AVERAGE HEATING ENERGY USE, KWH |
|---|---|---|---|
| **JANUARY** | 46,900 | 336,273 | 173,514 |
| **FEBRUARY** | 62,500 | 448,125 | 285,366 |
| **MARCH** | 30,300 | 217,251 | 54,492 |
| **APRIL** | 29,600 | 212,232 | 49,473 |
| **MAY** | 27,550 | 197,534 | 34,775 |
| **JUNE** | 22,200 | 159,174 | 0 |
| **JULY** | 23,300 | 167,061 | 0 |
| **AUGUST** | 22,600 | 162,042 | 0 |
| **SEPTEMBER** | 27,200 | 195,024 | 32,265 |
| **OCTOBER** | 29,200 | 209,364 | 46,605 |
| **NOVEMBER** | 40,770 | 292,321 | 129,562 |
| **DECEMBER** | 53,830 | 385,961 | 223,202 |

The monthly average is based upon averaging the steam use of all the provided years. The average steam usage of June-August is averaged as a baseline steam usage with the difference being the monthly heating use. With the total steam used averaged, equation 5.2 is applied to calculate the equivalent kWh.

### 5.1.4 Total HVAC Energy Use

The HVAC energy use of the building is a combination of all the systems used for conditioning and delivering air to the building. This system includes chillers, cooling towers, air handling units, boilers, and control systems. January and December energy use is useful to isolate the chiller and cooling tower energy for Eaton Hall because the part of the HVAC system used for heating the air is the district heat provided on campus. While this is useful for a large component of HVAC energy use, the ventilation component of the HVAC system runs at times at varying levels of production. This component is required to provide a full HVAC building estimate of the degradation performance.

With no installed methods of monitoring the operation of the air handling unit for ventilation, an estimate must be chosen. The *Buildings Energy Data Book 2012*, provided by the Energy Information Agency, the 2010 commercial building end use energy for ventilation was 8.9% of the total energy used. For the purposes of evaluating EDEC, an estimate of 8.9% of baseline and increase occupant electricity energy use will be assumed. Although this additional ventilation requirement is identified as part of the baseline, the total impact on the building HVAC energy use total is small compared to direct data. This makes the baseline occupant and increased occupant energy use for Eaton 3722 kWh/day and 670 kWh/day, respectively. The baseline and increased ventilation energy use per day would then be estimated at 364 kWh/day and 66 kWh/day. Any other increased to ventilation would be included in the use of the chillers and cooling tower estimates.

The chiller and cooling tower estimated energy per month is the difference of the average monthly energy use and the occupant and ventilation uses. This chiller/cooling tower energy use is shown in the following table:

**Table 5.5 HVAC Energy Use per Month**

| Month | Average Elec. Monthly Energy Use, kWh | Baseline and Increase Occupant Use, kWh | Ventilation Use, kWh | Chiller/Cooling Tower And Excess Ventilation Use, kWh |
|---|---|---|---|---|
| **January** | 139924 | 127,442 | 12,472 | 10 |
| **February** | 162393 | 122,976 | 12,040 | 27377 |
| **March** | 154,090 | 130,122 | 12,736 | 11232 |
| **April** | 181770 | 113,670 | 11,118 | 56982 |
| **May** | 182682 | 125,432 | 12,274 | 44976 |
| **June** | 188424 | 118,360 | 11,580 | 58484 |
| **July** | 227351 | 123,422 | 12,076 | 91853 |
| **August** | 216000 | 119,402 | 11,680 | 84918 |
| **September** | 212234 | 131,760 | 12,900 | 67574 |
| **October** | 173171 | 133,472 | 13,066 | 26633 |
| **November** | 188113 | 129,080 | 12,636 | 46397 |
| **December** | 140660 | 128,112 | 12,538 | 10 |

The distribution of monthly HVAC electrical energy use is provided in Figure 5.8.

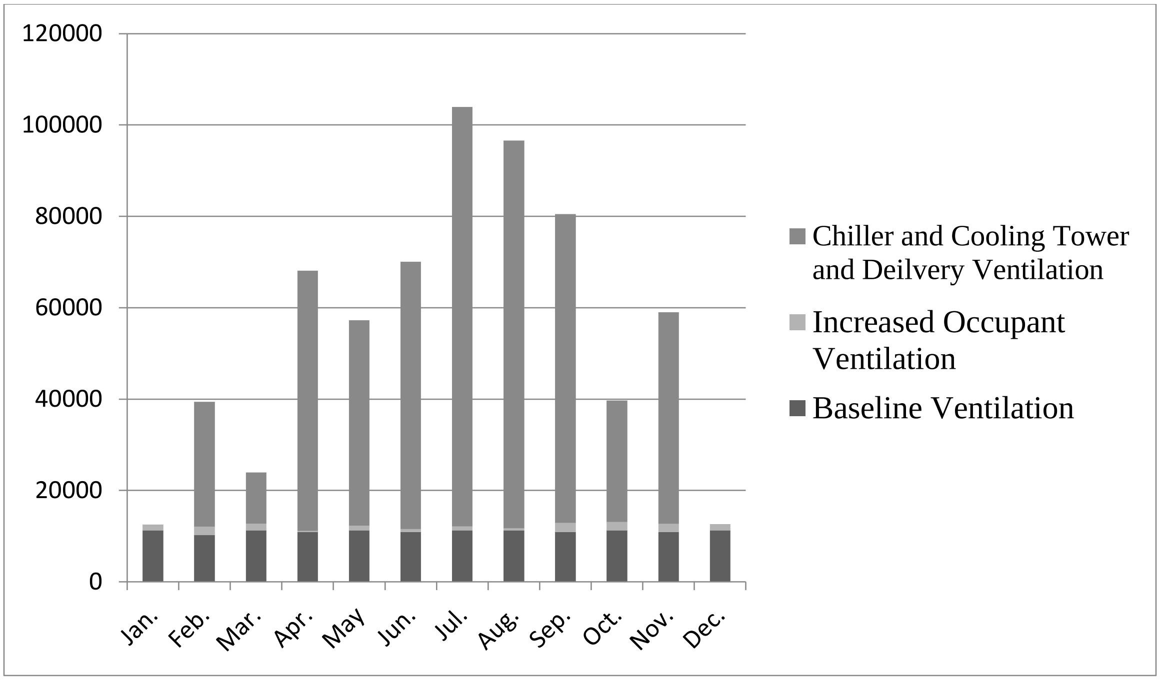



**Figure 5.8 Energy Use per Month, kWh**

As is shown, the main trend for electrical use for HVAC is a curve with the maximum energy use is in the summer and the minimum energy used in the winter.  With the heating provided though other energy distribution sources, this curve is reasonable for Kansas.  The dips within March and October would most likely be based upon when the energy data was collected in comparison the neighboring months.  For example, the data collection for can be based on collection every four and a half weeks, 31-32 days.  This would add five additional days to February's totals and reduce the total days for the October data collection.  This data would be present in the chiller/cooling tower and ventilation distribution energy use since it is not regulated by a daily average value.

### 5.1.5 Comparison to National Average

To review if the energy use is properly distributed for Eaton Hall, the energy estimation will be compared to the *Buildings Energy Data Book 2012*. While the building's distribution would not be exactly similar to the commercial building average, the analysis would show if the actual values from Eaton hall are reasonable. The 2010 Commercial energy building use distribution is shown below:

**Table 5.6 Breakdown of Commercial Energy Use**

| Energy Use | Percentage |
|---|---|
| Lighting | 20.2% |
| Space Heating | 16.0% |
| Space Cooling | 14.5% |
| Ventilation | 9.1% |
| Refrigeration | 6.6% |
| Water Heating | 4.3% |
| Electronics | 4.4% |
| Computers | 3.6% |
| Cooking | 1.4% |
| Other | 14.5% |

The total estimated energy used by the building for ventilation and space cooling is 663,563 kWh/year with the total electrical building energy estimated at 2,167,918 kWh/year on average. Including the yearly building average steam use 2,982,362 kWh/yr and a heating average total of 1,033,556 kWh/yr with a total building average of 5,150,280 kWh/yr. This estimated HVAC energy use is 32.9%, which is lower than the 39.6% that is the national average. One of the factors making this percentage low, is that not all of the delivered energy is included, such as natural gas. Also the energy used by district steam can use more energy than local steam. Even with this percentage being low, the estimated distribution is reasonable when comparing the local climate to other climates within the United States.  Kansas is in a region where high summer temperature are experienced without coastal cooling.  Therefore the range is valid for the building.

### 5.1.6 Long-Term Estimate with Provided Data

The building's long-term energy use to be evaluated with current methods, the cumulative energy added would be linear.  This linear relationship is to include the sum of the average energy used to create an approximation of what could happen with the building with being properly maintained.  Eaton Hall will be evaluated in the same manner to compare to EDEC.  The timespan of this energy total will be 30 years from construction, the replacement age of certain pieces of HVAC equipment.  The total electrical energy used for 30 years for Eaton all is estimated at 154,508,400 kWh.  The increase is provided below:

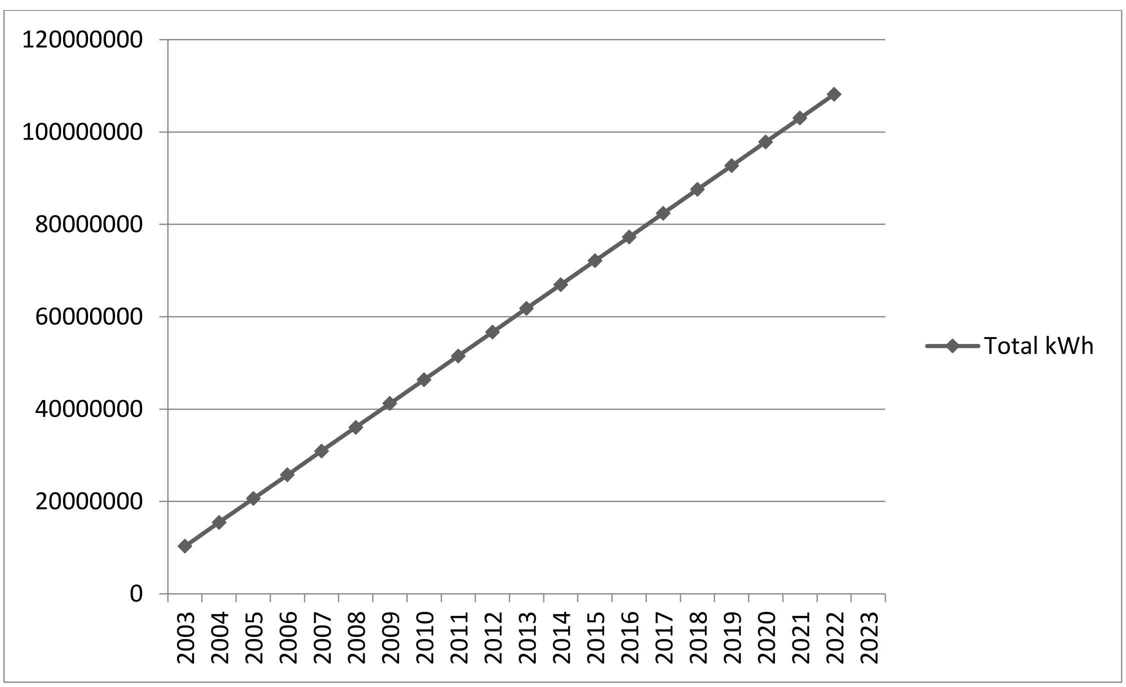



**Figure 5.9 Electrical Energy Estimate, Basic Methods**

This energy amount times the current cost $0.0755per kWh/year would make a 30 year HVAC operational estimated cost $4.910 Million. These two totals will be compared to EDEC numbers to review how much of a possible increase in estimates over the 30 year total.

### 5.1.7 EDEC Calculation

To compare the degradation over years, a relationship of energy use to climate would have to be acknowledged. The median monthly average temperature change per year is shown in the following table.

**Table 5.7 Median Temperature Difference, Lawrence, Fahrenheit**

| Year | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003-2004 | 1.7 | -0.9 | 4.1 | -1.9 | 1.8 | 0.7 | -6.1 | -8 | 4.5 | -2.9 | 0.2 | N/A |
| 2004-2005 | 0.2 | 7.5 | -4.7 | 0.2 | -2.7 | 3.2 | 2.1 | 3.6 | 0.8 | -0.1 | N/A | N/A |
| 2005-2006 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2006-2007 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2007-2008 | N/A | N/A | N/A | N/A | -6.6 | 0.5 | -0.8 | -8.9 | -4.1 | -4.3 | 0.5 | -0.1 |
| 2008-2009 | 2.2 | 10.5 | 3 | 2.6 | 2.5 | 1 | -3.6 | -1.1 | -1.2 | -4.8 | 5.8 | -0.6 |
| 2009-2010 | -5.9 | -11.5 | 0.2 | 7.8 | -1.4 | 1.9 | 5.6 | 6.9 | 5.2 | 10 | -3.7 | 3.6 |
| 2010-2011 | 1.7 | 2.2 | 0.2 | -2.9 | 0.9 | -0.7 | 5.3 | 0.4 | -3.4 | -0.5 | 1 | 6.8 |
| 2011-2012 | 12.3 | 9.7 | 16 | 5 | 7.9 | 1.9 | 1.4 | -2.8 | 3.7 | -2.8 | 2.8 | -0.7 |
| 2012-2013 | -2.6 | -3.6 | -21.7 | -11.6 | -7.3 | -3.8 | -9 | -1.7 | | | | |

A comparison of these values with the average monthly high and low values can give a general idea if the system is performing among weather data. This is to find any outlining climate changes that can affect the general trend of equipment use and efficiency. The HVAC energy use is mostly consistent with the temperature changes within the area.

The calculation of degradation for Eaton Hall's HVAC system will be based upon NREL's equations for split system HVAC equipment as discussed in Chapter 5. The use of their formulas for the preliminary degradation curves is due to a lacking of degradation formulas for commercial HVAC equipment due to their system complexity. With a HVAC system with similar needs, there are infinite design options compared to spilt systems, making a degradation formula more complex to derive. The basic HVAC degradation usage formula is:

$$E_{Mt} = \frac{E_b}{\left(1-M_f\right)^t} \qquad \textbf{(5.3)}$$

Where:

$E_{Mt}$ = Energy modified for degradation, kWh/yr

$E_b$ = Energy baseline for initial equipment year, kWh/yr

$M_f$ = Modification factor

t = time from initial equipment year

The use modification factor is based upon the maintenance of the system. With the factor based upon a split system originally, the maintenance of the air handling unit, chillers, and cooling tower would be on one factor; while the boiler would be set on a different maintenance factor. With NREL's base formula, the modification factor for a well maintained system and a poorly maintained system is 0.01 and 0.02, respectfully. This shows that maintenance can cause a 100% increase in yearly degradation when deferred. With the current monitoring of the University of Kansas and the large cost associated with the campus energy cost, it will be initially assumed that the system is well maintained. A large tonnage HVAC AHU, Chiller and Cooling tower can have a standard operating lifespan of 20-30 years. Based upon the baseline yearly energy use, the deprecation of the HVAC use for modifier factor of 0.01 after one year:

$$E_{Mt} = \frac{663{,}563}{(1 - 0.01)^{2-1}}$$

$$E_{Mt} = 670{,}266\ kWh/yr$$

The total building increase is modeled by:

$$\sum_{t=1}^{30} E_{Mt} = \frac{E_b}{\left(1 - M_f\right)^{t-1}} \qquad \textbf{(5.4)}$$

The degradation curve follows the baseline energy from the final year of data. For Eaton Hall the modified energy baseline is $E_{b2012}$ = 672,437 kWh/yr. The total HVAC energy for both modifiers is displayed in Table 5.8:

**Table 5.8 EDEC Increase with Various Modifiers**

| Year | 0.01 = Modifier, Maintained | 0.02 = Modifier, Not Maintained |
|---|---|---|
| **2012** | 663,563 | 663,563 |
| **2013** | 670,266 | 677,105 |
| **2014** | 677,036 | 690,924 |
| **2015** | 683,875 | 705,024 |
| **2016** | 690,783 | 719,412 |
| **2017** | 697,760 | 734,094 |
| **2018** | 704,808 | 749,076 |
| **2019** | 711,928 | 764,363 |
| **2020** | 719,119 | 779,962 |
| **2021** | 726,383 | 795,880 |
| **2022** | 733,720 | 812,122 |
| **2023** | 741,131 | 828,696 |
| **2024** | 748,617 | 845,608 |
| **2025** | 756,179 | 862,866 |
| **2026** | 763,817 | 880,475 |
| **2027** | 771,533 | 898,444 |
| **2028** | 779,326 | 916,780 |
| **2029** | 787,198 | 935,489 |
| **2030** | 795,149 | 954,581 |
| **2031** | 803,181 | 974,062 |
| **2032** | 811,294 | 993,941 |

With the original estimated energy modifier, the changes are high. With the depreciation model based upon the building's use, the yearly HVAC energy use for 2004 is 634,364 kWh/yr. Comparing this number with the 2012 energy use total:

$$672{,}437 = \frac{634{,}364}{\left(1 - M_{fi}\right)^{8-1}}$$

$$M_{fi} = 0.008292$$

Therefore, for Eaton Hall the modifier used will be 0.008292. The new modifier is used and the last 20 year lifespan of the equipment is:

**Table 5.9 HVAC Electrical Increase for Eaton Hall, kWh**

| Year | 0.008292 = Modifier |
|---|---|
| **2012** | 663,563 |
| **2013** | 669,111 |
| **2014** | 674,706 |
| **2015** | 680,347 |
| **2016** | 686,036 |
| **2017** | 691,772 |
| **2018** | 697,556 |
| **2019** | 703,389 |
| **2020** | 709,270 |
| **2021** | 715,201 |
| **2022** | 721,181 |
| **2023** | 727,211 |
| **2024** | 733,291 |
| **2025** | 739,422 |
| **2026** | 745,605 |
| **2027** | 751,839 |
| **2028** | 758,125 |
| **2029** | 764,464 |
| **2030** | 770,856 |
| **2031** | 777,302 |
| **2032** | 783,801 |
| **2033** | 790,355 |

The yearly HVAC increase is shown in the figure below:

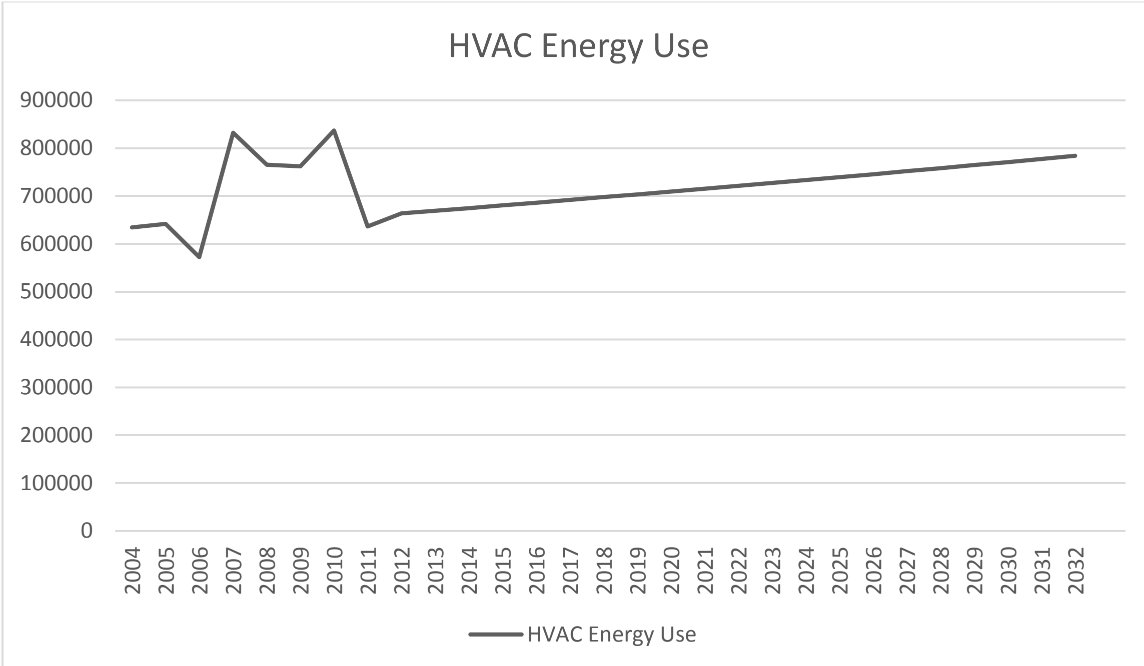



**Figure 5.10 EDEC Total Electrical Energy Increase**

For the district steam, the modification factor is 0.005, which makes the depreciation of the boiler for 30 years in Table 5.10.

**Table 5.10 EDEC Steam Increase, kWh**

| Year | Yearly Average, kWh |
|---|---|
| **2003** | 1,033,556 |
| **2004** | 1,033,556 |
| **2005** | 1,033,556 |
| **2006** | 1,033,556 |
| **2007** | 1,033,556 |
| **2008** | 1,033,556 |
| **2009** | 1,033,556 |
| **2010** | 1,033,556 |
| **2011** | 1,033,556 |
| **2012** | 1,033,556 |
| **2013** | 1,038,750 |
| **2014** | 1,043,970 |
| **2015** | 1,049,216 |
| **2016** | 1,054,488 |
| **2017** | 1,059,787 |
| **2018** | 1,065,113 |
| **2019** | 1,070,465 |
| **2020** | 1,075,844 |
| **2021** | 1,081,250 |
| **2022** | 1,086,684 |
| **2023** | 1,092,145 |
| **2024** | 1,097,633 |
| **2025** | 1,103,148 |
| **2026** | 1,108,692 |
| **2027** | 1,114,263 |
| **2028** | 1,119,863 |
| **2029** | 1,125,490 |
| **2030** | 1,131,146 |
| **2031** | 1,136,830 |
| **2032** | 1,142,543 |
| **Total** | 30,990,330 |

The gradual increase for building efficiency does not account for the weather changes between each year. The electrical efficiency change increase for 20 years is 19.1% of the baseline. The total building energy for the first 30 year with degradation included is the baseline occupant energy and the sum of the degradation totals. The total degradation for electrical is 1,356,017 kWh and steam 1,126,200 kWh/yr. For the 30 year timeframe, the

Eaton Hall degradation total for the building is 161,754,531 kWh. This is an increase of 1.53% increase from the baseline, which is a costs the owner $177,000 or more. This degradation will reset for each equipment change out.

With Eaton Hall, the maintenance is at a high level, but with a poorly maintained building, how much will the total energy degradation. The electrical modifier is 0.02 and the steam modifier is 0.015. The 30 year electrical use is 3,598,307 kWh degradation and a total of 74,542,311 kWh. The 30 year heating degradation is 4,033,154 kWh and a total energy use is 93,503,999 kWh. The total energy is 168,046,310 kWh a degradation increase of 4.54% with a cost increase of $643,000 or more.

Both models show the maintenance extreme; well and poorly maintained, but the model does not include the variations of maintenance that would be present within the world. This maintenance would vary based upon many factors such as the age of the equipment because of reduction of repair schedules, availability of replacement material, or deferment from cost increases from repairs. These maintenance changes need to be modeled in some form within the modifier variable. In the simplest form, the modifier could be increase from the starting modifier to the worst case with linear interpolation. This enhanced modifier is shown in equation 5.5.

$$M_{fE} = M_{int} + \left(\frac{(M_{end} - M_{int})}{t_{eq}}\right) * (t_n - 1) \qquad \textbf{(5.5)}$$

Where:

$M_{fE}$ = Enhanced modifier factor for year n

$M_{int}$ = Initial modifier factor

$M_{end}$ = End of life modifier factor

$t_{eq}$ = Total years left of equipment

$t_n$ = Year of analysis, n

With this enhanced modifier, the energy increases in a geometric rate. These values are shown in the appendix. The degradation increase for electrical and steam in this situation is 2,862,037 kWh and 3,107,162 kWh respectfully. Making a total energy degradation increase of 2.11% overall and an increase of 58% within degradation totals for the best case. This equation will be reviewed in the next chapter. With the operational energy degradation calculated, to get a full picture, the embodied energy calculations need to be reviewed.

### 5.2 Case Study 2

The second case study is to analyze the increase of embodied energy through the addition of material through degradation methods. This case study will use the Measurement, Materials and Sustainable Environment Center, $M^2SEC$, in Lawrence, Kansas in the University of Kansas Campus.

**Figure 5.11 M2SEC**

The 47,000 square foot building, contains laboratories and some offices. This building opened in 2012, and was constructed under the National Recovery Act. With the terms stipulated within the act, a detailed account of building materials was needed to verify the buy American requirement.

The embodied energy of the building will use the material data provided by the J.E. Dunn, the construction manager for the construction of the building. The quantity data is combined with the ICE V 2.0 database discussed in Chapter 3. The Inventory of Carbon and Energy Summary provides the embodied energy of the material per unit mass. The conversion of material to embodied energy is of MJ/kg, therefore conversion to metric is needed. The material is converted by calculating the mass of the material and finding the embodied energy multiplier for a comparable material. An example calculation follows:

The $M^2SEC$ material database is used to calculate the energy per disciple. An example of this calculation database is shown:

For 807 $ft^2$ of Ceramic Tile

$$EE = M_M * EE_F \qquad \textbf{(5.6)}$$

Where:

EE = Embodied Energy, MJ

$M_M$ = Mass of Material, kg

$EE_F$ = Embodied Energy Factor, MJ/kg

$$EE = 807\, ft^2 * 4.7\ \frac{lbs}{ft^2} * 0.443592 \frac{kg}{lbs} * 12\ \frac{MJ}{kg} * \frac{1\ kWh}{3.6\ MJ}$$

$$EE = 20{,}645\ kWh$$

A complete database is provided within the appendix. The total embodied energy for $M^2SEC$ per disciple is shown in Table 5.11.

.

**Table 5.11 Breakdown of Embodied Energy, kWh**

| Discipline | Embodied Energy, kWh | Percent of Total |
|---|---|---|
| **Excavation** | 1,309,273 | 12.71% |
| **Structural** | 1,923,250 | 18.68% |
| **Masonry** | 216,196 | 2.10% |
| **Carpentry** | 57,713 | 0.56% |
| **Roofing and Flashing** | 3,484,310 | 33.84% |
| **Doors and Glazing** | 732,508 | 7.11% |
| **Plaster and Ceilings** | 1,360,218 | 13.21% |
| **Flooring** | 38,375 | 0.37% |
| **Equipment** | 395,842 | 3.84% |
| **Fire Protection and Plumbing** | 24,537 | 0.24% |
| **HVAC** | 230,969 | 2.24% |
| **Electrical** | 524,596 | 5.09% |
| **Total** | 10,297,787 | 100.00% |

For building material degradation, the addition of material for replacements and repairs is key. To predict the total increase in embodied energy, the replacement schedule for equipment is needed. From the CBECS, buildings have, on average a major renovation every 20-30 years. A major renovation is defined as a 25% value of the building is the minimum budget of the renovation. This definition does not explain what materials are affected within a remodel. A survey conducted for Nonresidential Remodeling and Renovation in California by the U.S. Department of Energy, reviewed which equipment/materials are affected by renovations. The breakdown of the frequency of equipment/materials changed during a renovation is provided.

**Table 5.12 Renovation Frequency**

| Sub Component Renovation | Percent of Renovation projects Included |
|---|---|
| **Lighting** | 76% |
| **HVAC Equipment** | 72% |
| **Partitions** | 60% |
| **HVAC Distribution** | 46% |
| **Power Systems** | 37% |
| **Windows and Doors** | 19% |
| **Roofing** | 10% |
| **External Elements** | 9% |

Using these frequency guidelines, an estimated major renovation prediction will be modeled. The HVAC equipment will be replaced within the same schedule as used in the first case study, 30 years. The lighting will be replaced during the renovation times with 10% of internal walls replaced to simulate internal remodeling. This internal wall changes will also affect the wall assemblies, such as electrical wiring. The assumption of increase in repairs will be facilitated by the modifier formula introduced at the end of the first case study. An assumption of a 0.9% repair need per year will be evaluated for each equipment replacement or renovation.

The assumed lifespan of this building is 100 years, this is because of it being of an educational/institutional use. With the HVAC equipment, there would be replacements at building year 30 and 60 years. Following the HVAC replacement schedule would also include a replacement at 90 years, but since the planned lifespan of the building is 100 years it is unlikely that the equipment would be replaced for the last 10 years of the lifespan. The major renovation schedule will use a schedule of 25 years with the schedule of building year 25, 50, and 75. The repair increases for HAVAC equipment is

24%, 41%, 55% increase in embodied energy for remaining specific material such as ductwork and wiring.  The repair increased for renovations is 20%, 36%, and 49% respectfully as derived from constant repairs of 0.9% per year.  This increase is to simulate the repairs undertaken on the building that are more difficult to quantify in a long term basis.  For the HVAC replacement increases, they are shown in Table 5.13.

**Table 5.13 Equipment Replacement Analysis**

| Building Year | Without Repair Factor | With Repair Factor |
|---|---|---|
| **30** | 221,140 kWh | 274,214 kWh |
| **60** | 221,140 kWh | 331,807 kWh |
| **90** | 221,140 kWh | 342,767 kWh |
| **Total** | 663,420 kWh | 948,788 kWh |

For Major renovation the table follows:

**Table 5.14 Renovation Analysis**

| Building Year | Without repair Factor | With Repair Factor |
|---|---|---|
| **25** | 15,189 kWh | 18,227 kWh |
| **50** | 15,189 kWh | 20,657 kWh |
| **75** | 15,189 kWh | 22,632 kWh |
| **Total** | 45,567 kWh | 61,516 kWh |

The increase to the baseline embodied energy is a total of 709,000 kWh without a repair increase and 1,010,000 kWh with the repair assumption.  The total embodied energy increase for the building is 6.9% and 9.8%.  With HVAC equipment, the total increase is 287% and 410% without and with the repair assumption.  This change is significant for this section of the building's embodied energy.

# Chapter 6 Use of EDEC is Sustainability Accounting

With the degradation of the building calculated, how to use the information is the next problem. EDEC is to aid in the reliability of a building's energy estimates which currently are present the industry. The building owners become disappointed when the systems to not perform within long term parameters. Also, with the push to net zero and carbon neutral buildings, the estimated for renewable systems are based upon the initial data, without any addition to the post-construction embodied energy or operational energy performance changes. What this causes is a discrepancy on the actual total building energy being more than the assumed total building energy, making a net zero or carbon neutral building unattainable.

To review how EDEC affects net zero and carbon neutral calculations, a model building will be used to see the increases to the renewable energy systems caused by the degradation. This model building will use the operational energy from Eaton Hall and the embodied energy from $M^2$SEC. The basic review for these processes is to account for construction embodied energy and the yearly average power consumption. The building will be evaluated for 100 years. The assumed renewable energy for the analysis will be photovoltaic systems. The standard solar array used for measurement and economic purposes is the LG NeoN LG290N1C. The specific data for this solar array is as follows:

STC (standard testing conditions) rated output: 290 W

Module Efficiency: 17.7%

Module Degradation: 97% output first year, 0.7% reduction per year

Life Span: 25 years

Monocrystalline module

MSRP: $422

From the PPVWatts online calculator provided by NREL, the yearly energy produced for this solar array for Lawrence, KS is 379 kWh (National Renewable Energy Laboratory 2012). The solar array will be replaced every 25 years, therefore the panels would need to account for 25% of the construction embodied energy as well as the solar array embodied energy and the yearly operational energy.

With the basic analysis methods, the construction embodied energy is 10,297,787 kWh. The yearly embodied energy is 2,167,918 kWh/yr for electrical use and 2,982,362 kWh/yr for steam usage. The amount of construction embodied energy to be accounted for each set of solar equipment is:

$$S_{EE} = \frac{EE}{SA_n} \qquad \textbf{(6.1)}$$

Where:

$S_{EE}$ = Building Embodied Energy for Solar array, kWh

EE = Building Embodied Energy, kWh

$SA_n$ = Number of solar arrays for lifespan of building

$$S_{EE} = \frac{10{,}297{,}787\ kWh}{4}$$

$$S_{EE} = 2{,}574{,}447\ kWh$$

The total energy needed to be offset to be carbon neutral per solar array is shown below:

**Table 6.1 Basic Analysis of Needed PV for Net-Zero and Carbon Neutral Accounting**

| YEAR | EMBODIED ENERGY | OPERATIONAL ENERGY | PV EMBODIED ENERGY | PV ARRAY AC POWER |
|---|---|---|---|---|
| **1** | 2,574,447 | 5,150,280 | 2,451,518 | 367.63 |
| **2** | 0 | 5,150,280 | 0 | 364.98 |
| **3** | 0 | 5,150,280 | 0 | 362.32 |
| **4** | 0 | 5,150,280 | 0 | 359.67 |
| **5** | 0 | 5,150,280 | 0 | 357.02 |
| **6** | 0 | 5,150,280 | 0 | 354.37 |
| **7** | 0 | 5,150,280 | 0 | 351.71 |
| **8** | 0 | 5,150,280 | 0 | 349.06 |
| **9** | 0 | 5,150,280 | 0 | 346.41 |
| **10** | 0 | 5,150,280 | 0 | 343.75 |
| **11** | 0 | 5,150,280 | 0 | 341.10 |
| **12** | 0 | 5,150,280 | 0 | 338.45 |
| **13** | 0 | 5,150,280 | 0 | 335.79 |
| **14** | 0 | 5,150,280 | 0 | 333.14 |
| **15** | 0 | 5,150,280 | 0 | 330.49 |
| **16** | 0 | 5,150,280 | 0 | 327.84 |
| **17** | 0 | 5,150,280 | 0 | 325.18 |
| **18** | 0 | 5,150,280 | 0 | 322.53 |
| **19** | 0 | 5,150,280 | 0 | 319.88 |
| **20** | 0 | 5,150,280 | 0 | 317.22 |
| **21** | 0 | 5,150,280 | 0 | 314.57 |
| **22** | 0 | 5,150,280 | 0 | 311.92 |
| **23** | 0 | 5,150,280 | 0 | 309.26 |
| **24** | 0 | 5,150,280 | 0 | 306.61 |
| **25** | 0 | 5,150,280 | 0 | 303.96 |
| **TOTAL** | 2,574,447 | 128,757,000 | 2,451,518 | 8,027.22 |

A non-solar degradation total for this building to be 13,698 solar arrays for net-zero energy, while the solar degradation total number of arrays 16,040 solar arrays every 25 years. The calculations are provided within the appendix. The total cost for net-zero and carbon neutral solar arrays are provided in Table 6.2.

**Table 6.2 PV Cost for Net-Zero and Carbon Neutral Analysis**

| Analysis type | Number of PV arrays for 25 years | Total PV arrays for Lifespan | Cost per 25 years | Total Costs |
|---|---|---|---|---|
| Net-Zero, no PV Degradation | 13,698 | 54,792 | $5,780,367 | $23,121,468 |
| Net-Zero, PV Degradation | 16,040 | 64,160 | $6,768,900 | $27,075,600 |
| Carbon Neutral, no PV Degradation | 14,708 | 58,832 | $6,206,729 | $24,826,916 |
| Carbon Neutral, PV Degradation | 16,668 | 66,672 | $7,033,836 | $28,135,344 |

With both processes, the more accurate cost increase for a basic review of net-zero and carbon neutral systems are an additional $4 million. This is a significant amount over for the building owner when deciding if the cost of these systems are economically justified.

This is a basic analysis, without the EDEC review, problems with the performance of the system could cause legal issues for the designer. With EDEC, balancing of the energy is needed. The total energy of each PV system will compare the EDEC data based upon two methods, without the embodied repair. The total building energy tables are shown below:

**Table 6.3 EDEC PV Analysis for year 0-25**

| YEAR | EMBODIED | BASE OP. ENERGY | HVAC EDEC | BOILER EDEC |
|---|---|---|---|---|
| **1** | 10,297,787 | 3,453,161 | 663,563 | 1,033,556 |
| **2** | 0 | 3,453,161 | 669,111 | 1,038,750 |
| **3** | 0 | 3,453,161 | 674,706 | 1,043,970 |
| **4** | 0 | 3,453,161 | 680,347 | 1,049,216 |
| **5** | 0 | 3,453,161 | 686,036 | 1,054,488 |
| **6** | 0 | 3,453,161 | 691,772 | 1,059,787 |
| **7** | 0 | 3,453,161 | 697,556 | 1,065,113 |
| **8** | 0 | 3,453,161 | 703,389 | 1,070,465 |
| **9** | 0 | 3,453,161 | 709,270 | 1,075,844 |
| **10** | 0 | 3,453,161 | 715,201 | 1,081,250 |
| **11** | 0 | 3,453,161 | 721,181 | 1,086,684 |
| **12** | 0 | 3,453,161 | 727,211 | 1,092,145 |
| **13** | 0 | 3,453,161 | 733,291 | 1,097,633 |
| **14** | 0 | 3,453,161 | 739,422 | 1,103,148 |
| **15** | 0 | 3,453,161 | 745,605 | 1,108,692 |
| **16** | 0 | 3,453,161 | 751,839 | 1,114,263 |
| **17** | 0 | 3,453,161 | 758,125 | 1,119,863 |
| **18** | 0 | 3,453,161 | 764,464 | 1,125,490 |
| **19** | 0 | 3,453,161 | 770,856 | 1,131,146 |
| **20** | 0 | 3,453,161 | 777,302 | 1,136,830 |
| **21** | 0 | 3,453,161 | 783,801 | 1,142,543 |
| **22** | 0 | 3,453,161 | 790,355 | 1,148,284 |
| **23** | 0 | 3,453,161 | 796,963 | 1,154,054 |
| **24** | 0 | 3,453,161 | 803,627 | 1,159,854 |
| **25** | 0 | 3,453,161 | 810,346 | 1,165,682 |
| **TOTAL** | 10,297,787 | 86,329,025 | 18,365,339 | 27,458,748 |

**Table 6.4 EDEC PV Analysis for year 26-50**

| YEAR | EMBODIED | BASE OP. ENERGY | HVAC EDEC | BOILER EDEC |
|---|---|---|---|---|
| **26** | 15,189 | 3,453,161 | 817,122 | 1,171,540 |
| **27** | 0 | 3,453,161 | 823,954 | 1,177,427 |
| **28** | 0 | 3,453,161 | 830,843 | 1,183,344 |
| **29** | 0 | 3,453,161 | 837,790 | 1,189,290 |
| **30** | 0 | 3,453,161 | 844,795 | 1,195,266 |
| **31** | 221,140 | 3,453,161 | 663,563 | 1,033,556 |
| **32** | 0 | 3,453,161 | 669,111 | 1,201,273 |
| **33** | 0 | 3,453,161 | 674,706 | 1,201,273 |
| **34** | 0 | 3,453,161 | 680,347 | 1,201,273 |
| **35** | 0 | 3,453,161 | 686,036 | 1,201,273 |
| **36** | 0 | 3,453,161 | 691,772 | 1,201,273 |
| **37** | 0 | 3,453,161 | 697,556 | 1,201,273 |
| **38** | 0 | 3,453,161 | 703,389 | 1,201,273 |
| **39** | 0 | 3,453,161 | 709,270 | 1,201,273 |
| **40** | 0 | 3,453,161 | 715,201 | 1,201,273 |
| **41** | 0 | 3,453,161 | 721,181 | 1,201,273 |
| **42** | 0 | 3,453,161 | 727,211 | 1,201,273 |
| **43** | 0 | 3,453,161 | 733,291 | 1,201,273 |
| **44** | 0 | 3,453,161 | 739,422 | 1,201,273 |
| **45** | 0 | 3,453,161 | 745,605 | 1,201,273 |
| **46** | 0 | 3,453,161 | 751,839 | 1,201,273 |
| **47** | 0 | 3,453,161 | 758,125 | 1,201,273 |
| **48** | 0 | 3,453,161 | 764,464 | 1,201,273 |
| **49** | 0 | 3,453,161 | 770,856 | 1,201,273 |
| **50** | 0 | 3,453,161 | 777,302 | 1,201,273 |
| **TOTAL** | 236,329 | 86,329,025 | 18,534,752 | 29,774,603 |

A more complete listing of total building lifespan energy is included in the appendix. With the EDEC variables included, the increases to total energy change the estimated number of PV arrays for Net-Zero and Carbon Neutral above the basic assumptions. The finished needed PV arrays for Net-zero and carbon neutral analysis without and with embodied energy repairs included as shown in Table 6.5 and Table 6.6.

**Table 6.5 PV Analysis without Embodied Repair**

| YEAR | NET-ZERO PV ARRAYS | NET-ZERO PV COST | CARBON NEUTRAL PV ARRAY | CARBON NEUTRAL PV COST |
|---|---|---|---|---|
| **0-25** | 15,907 | $7,030,754 | 16,241 | $7,178,662 |
| **26-50** | 15,907 | $7,030,754 | 16,241 | $7,178,662 |
| **51-75** | 15,907 | $7,030,754 | 16,241 | $7,178,662 |
| **76-100** | 15,907 | $7,030,754 | 16,241 | $7,178,662 |
| **TOTAL** | 63,627 | $28,123,016 | 64,965 | $28,714,649 |

**Table 6.6 PV Analysis with Embodied Repair**

| YEAR | NET-ZERO PV ARRAYS | NET-ZERO PV COST | CARBON NEUTRAL PV ARRAY | CARBON NEUTRAL PV COST |
|---|---|---|---|---|
| **0-25** | 15,907 | $7,030,754 | 16,247 | $7,180,990 |
| **26-50** | 15,907 | $7,030,754 | 16,247 | $7,180,990 |
| **51-75** | 15,907 | $7,030,754 | 16,247 | $7,180,990 |
| **76-100** | 15,907 | $7,030,754 | 16,247 | $7,180,990 |
| **TOTAL** | 63,627 | $28,123,016 | 66,262 | $28,723,960 |

The degradation analysis was performed with the basic linear modification factor, this factor, is a more basic review of user maintenance performance. To achieve a more realistic result, the sliding modifier variable that was discussed in the previous chapter is needed. This modifier is based on the yearly linear interpolation between the lowest modifier for the first year and the highest for the final year, increasing steadily throughout. This calculation is provided in the appendix, and the results are provided for the PV analysis below:

**Table 6.7 PV Analysis of Sliding Degradation with Embodied Repair**

| YEAR | NET-ZERO PV ARRAYS | NET-ZERO PV COST | CARBON NEUTRAL PV ARRAY | CARBON NEUTRAL PV COST |
|---|---|---|---|---|
| **0-25** | 16,793 | $7,422,587 | 17,134 | $7,573,148 |
| **26-50** | 16,793 | $7,422,587 | 17,134 | $7,573,148 |
| **51-75** | 16,793 | $7,422,587 | 17,134 | $7,573,148 |
| **76-100** | 16,793 | $7,422,587 | 17,134 | $7,573,148 |
| **TOTAL** | 67,173 | $29,690,348 | 68,535 | $30,292,590 |

This shows an increase within the estimated PV array totals and cost. While this reduces the chances that an owner would voluntarily attempt these sustainability measures, the actual total cost would be more realistic, aiding in a better informed decision. These changes help sustainability move to the next step needed in analysis, gaining better information to combine all current knowledge into one unified system.

# Chapter 7 Future Work and Conclusions

The EDEC process is iterative with the inclusion of more data and information. The future work for the curves is to research more accurate maintenance factors for different HVAC equipment each one of these systems. A series of phases are needed to move EDEC from an early analysis method to a highly reliable system. These phases are:

Phase 1:

- Increase building energy tracking system data
- Compile large sample Building energy use data
- Track maintenance and HVAC efficiency for multiple type of equipment and sizing

Phase 2:

- Fully investigate the relationship between occupancy changes and HVAC efficiency
- Review construction quality on long term building maintenance
- Track maintenance and HVAC efficiency for multiple types of design methodology

Phase 3:

- Online database and calculator for professional design work.

Phase 4:

- Integrate real time tracking system into building control systems for automatic updates
- Create easy to read equipment data sheets for owner and designer use

The collection of long term HVAC equipment data is needed to refine the Phase 1 prediction models. This collection would be done by measuring the equipment's coefficient of performance over the lifespan of the system. This collection would also need to have accurate documentations of maintenance and repairs of the equipment to establish a rages of degradation modifiers. This data needs to be for different models of HVAC equipment and sizes to create a more unified production curve. The equipment running schedule would be needed to compare the equipment age and loads to estimate the performance losses. This load and usage data would be needed to accurately compare the performance from different buildings.

Phase 2 objectives would be used to add a second level of accuracy to the EDEC formulas. The comparison of changes in occupancy to load performance can aid in the estimation of changes to the performance curve when there are long term changes in occupancy, such as seasonal or educational use. Another change to the form would be long term monitoring of the repair schedules for buildings of different construction quality and equipment. This review of repair records would create an accurate model of embodied energy changes. The investigation would need to be throughout the life of the buildings.

The third and fourth phase would be to compile all the collected data into an online database for integration into professional design programs. This integration could be used in Building Information Modeling to automatically add the degradation models to performance estimates. The changes would aid in more realistic models for the use of renewable systems and carbon estimates. With these models integrated, the systems would be used regularly to and could be introduced into sustainability programs such as LEED.

### 7.1 Discussion

With EDEC, the practical uses would be for property energy management or other large buildings. The EDEC system can be used by the facilities management to monitor the maintenance schedule and its impact. EDEC can be used not only to monitor energy accounting for sustainability, but can also be used proactivity to balance maintenance and energy use to reduce the total building impact by reducing waste.

EDEC can be used to predict the total commercial rental property embodied energy. The analysis would take into account the frequency of the internal changes of the building between multiple tenant finishes. This prediction should be included within the energy accounting. The changes to the internal building use would be important to the total building energy amount. This would also define the occupancy of the space and how an HVAC system would perform between multiple tenant changes in one space.

With other building types such as factories, the designer would need to estimate the total number of remodels the building would experience over the lifespan to estimate the total embodied energy of the building more accurately.

For the operational energy, EDEC can be used in the decision making process of maintenance and replacement of equipment. With monitoring of the system equipment and repair schedule, trends can be noted to ensure that repairs are done in an effective and cost efficient manner. With natural degradation occurring with the operation of the system, repairs are needed to reduce this degradation. With repair monitoring, a manager could not the frequency of repairs and see the total effectiveness to the system. If the effectiveness is low, the manager could choose to defer the maintenance to when it would be more profitable. Of the other side, the manager could note that maintenance was lacking, adding extra wear to the system, necessitating more costly repairs in the future.

Also, the operational energy can be used to decide the replacement schedule of the equipment. With reviewing the degradation rate of equipment, the increase in energy use can be predicted. The energy use increase can be compared to new equipment costs to find the most cost effective times to replace the system. The energy use can be compared to find the even energy use point to maximize the total building energy savings. Also, included in this analysis can be reviewed for the breakeven point, saving money for the building manager. The practical applications of EDEC would be effective in exploiting the total building energy savings and cost reduction of equipment and maintenance.

## 7.2 Conclusions

The results for EDEC models are an increase to the total building energy, predicting a more realistic performance over the lifespan of the building. This is a jump for sustainability accounting, by acknowledging that a building does not exist in a closed system, but in a system with countless factors affecting it at all point in its' lifespan. For the estimation of embodied energy, the increase by accounting for the replacement for HVAC equipment resulted in a 6.4% and a 9.2% increase without and with repair estimates. This change is less than 0.1% of the total lifetime energy of the building.

For the Operational Energy use of the building the electrical HVAC equipment had a 27.3% change in energy performance over the lifespan of the equipment. For steam the performance change over 30 years was estimated at 15.6%. The equipment lifespan increase of the total energy is 13.1% for electricity and 7.6% for steam. This is an electrical increase of at least $197,000 for the lifespan of the equipment. Although this is small for the total equipment electrical cost of $1.5 million, to the owners paying the cost, the increase would aid in justification of repairs or replacement. When introducing the sliding degradation factor to the calculations, the electrical HVAC systems have a 77.5% increase in energy use. The total building lifespan energy increase is 25.9% for electrical and 17.8% for steam energy use. This energy increase results in an equipment lifespan cost increase of $424,550 and $296,116 for electrical and steam, respectfully. This results in a total equipment lifespan increase of $720,669. The building's lifetime energy cost increase is at least $2,204,081 for 100 years. This increase in cost is significant enough to warrant a review of owner maintenance schedules and reviews on long term equipment performance.

From the use of EDEC, a more complete picture can be devolved how a building would perform over the course of the building lifespan. Including degradation into net-zero and carbon neutral accounting increases the total building energy. This increase in energy creates a better system of analysis to use in the process of moving to the next stage of sustainability. With this degradation included, the goals of net-zero for new construction within a couple of decades may be unrealistic. This new accounting will make it possible for buildings to fully cover their total energy, increasing reliability of design parameters in the view of the owners.

The utilization of EDEC can be done for multiple skill levels when fully implemented in the future. This would have the basic systems for the homeowner to the large scale management of an engineering design firm. The only difference that separate the skill levels is the data. The more data provided, the better the accounting process will become. EDEC has shown a significant increase in the total lifetime building energy that, until now has been omitted. For society to evolve and continue, as much of the realistic variables within building performance need to be taken into account.  This system can be used for a single building or large campuses, as well.

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# Appendix

## Weather Data for Lawrence, Kansas

Monthly Average High

| Year | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003 | 37.9 | 42.4 | 56.4 | 69.4 | 75.3 | 81.1 | 92.8 | 91.9 | 76.4 | 71 | 54 | 37.5 |
| 2004 | 38.3 | 40.9 | 58.6 | 68.1 | 77.2 | 79.8 | 5.1 | 83.1 | 82.1 | 67.4 | 54.1 | NR |
| 2005 | 37.6 | 48.4 | 56 | 67.1 | 75.8 | 84.8 | 88 | 86 | 81.7 | 67.2 | NR | 31.8 |
| 2006 | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR |
| 2007 | NR | NR | NR | NR | 78.1 | 83 | 87.6 | 94.3 | 82.5 | 70.8 | 56.3 | 37.3 |
| 2008 | 37.2 | 37.6 | 52.2 | 60.8 | 73.9 | 84.2 | 88.4 | 86.3 | 77.4 | 66.8 | 53.9 | 39.7 |
| 2009 | 42 | 51.1 | 54.5 | 62.2 | 74.9 | 84.7 | 83 | 83.1 | 75 | 58 | 58.3 | 36.3 |
| 2010 | 29.3 | 34.5 | 52.4 | 71.2 | 71.9 | 86.6 | 88.4 | 91.6 | 80.2 | 71.9 | 55.9 | 41.3 |
| 2011 | 34.9 | 41.3 | 53.6 | 68.9 | 74.4 | 87 | 96.8 | 91.8 | 79 | 72.7 | 56.5 | 46.7 |
| 2012 | 48.5 | 47.7 | 69.8 | 72.8 | 81.9 | 90 | 98.7 | 89.6 | 80.7 | 66.3 | 60.7 | 46 |
| 2013 | 43.6 | 43.6 | 46.9 | 62.5 | 75 | 83.9 | 87.5 | 85.7 | | | | |

Monthly Average Median

| Year | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003 | 26.9 | 31.5 | 44.2 | 58.3 | 65.3 | 71.8 | 82.3 | 81.7 | 66.6 | 60.5 | 45.4 | 33.4 |
| 2004 | 28.6 | 30.6 | 48.3 | 56.4 | 67.1 | 72.5 | 76.2 | 73.7 | 71.1 | 57.6 | 45.6 | NR |
| 2005 | 28.8 | 38.1 | 43.6 | 56.6 | 64.4 | 75.7 | 78.3 | 77.3 | 71.9 | 57.5 | NR | 22.8 |
| 2006 | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR |
| 2007 | NR | NR | NR | NR | 68.6 | 73.7 | 78.5 | 83.5 | 70.3 | 58.8 | 42.8 | 28.3 |
| 2008 | 26.4 | 28 | 40.3 | 49.7 | 62 | 74.2 | 77.7 | 74.6 | 66.2 | 54.5 | 43.3 | 28.2 |
| 2009 | 28.6 | 38.5 | 43.3 | 52.3 | 64.5 | 75.2 | 74.1 | 73.5 | 65 | 49.7 | 49.1 | 27.6 |
| 2010 | 22.7 | 27 | 43.5 | 60.1 | 63.1 | 77.1 | 79.7 | 80.4 | 70.2 | 59.7 | 45.4 | 31.2 |
| 2011 | 24.4 | 29.2 | 43.7 | 57.2 | 64 | 76.4 | 85 | 80.8 | 66.8 | 59.2 | 46.4 | 38 |
| 2012 | 36.7 | 38.9 | 59.7 | 62.2 | 71.9 | 78.3 | 86.4 | 78 | 70.5 | 56.4 | 49.2 | 37.3 |
| 2013 | 34.1 | 35.3 | 38 | 50.6 | 64.6 | 74.5 | 77.4 | 76.3 | | | | |

Monthly Average Low

| Year | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003 | 15.8 | 20.7 | 31.9 | 47.2 | 55.2 | 62.5 | 71.8 | 71.5 | 56.8 | 49.9 | 36.8 | 29.3 |
| 2004 | 18.9 | 20.3 | 38.1 | 44.7 | 57.1 | 65.2 | 67.3 | 64.2 | 60 | 47.8 | 37 | NR |
| 2005 | 20 | 27.8 | 31.3 | 46.1 | 53 | 66.5 | 68.6 | 68.6 | 62.1 | 47.7 | NR | 14.5 |
| 2006 | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR |
| 2007 | NR | NR | NR | NR | 59.2 | 64.5 | 69.5 | 72.8 | 58 | 46.7 | 29.3 | 19.2 |
| 2008 | 15.6 | 18.5 | 28.4 | 38.6 | 50.2 | 64.3 | 67 | 63 | 54.9 | 42.2 | 32.7 | 16.8 |
| 2009 | 15.1 | 25.8 | 32.2 | 42.4 | 54.2 | 65.6 | 65.3 | 64 | 56.7 | 41.3 | 40 | 18.9 |
| 2010 | 16.2 | 19.5 | 34.6 | 48.9 | 54.4 | 67.5 | 70.9 | 6.2 | 60.2 | 47.5 | 34.8 | 21.1 |
| 2011 | 13.8 | 17.2 | 33.8 | 45.4 | 53.5 | 65.8 | 73.2 | 69.8 | 54.7 | 45.6 | 36.4 | 29.2 |
| 2012 | 24.9 | 30 | 49.5 | 51.6 | 61.8 | 66.6 | 74.1 | 66.3 | 60.2 | 46.5 | 37.8 | 28.7 |
| 2013 | 24.6 | 27 | 29.1 | 38.8 | 54.2 | 65.2 | 67.2 | 66.9 | | | | |

## Eaton Hall Electricity Usage

| YEAR | MONTH | ELECTRIC | ELECTRIC COST |
|---|---|---|---|
| **2003** | August | | |
| **2003** | September | | |
| **2003** | October | | |
| **2003** | November | 45,452.0 | $2,114.43 |
| **2003** | December | 162,260.0 | $7,502.09 |
| **2004** | January | 119,190.0 | $5,811.70 |
| **2004** | February | 142,380.0 | $6,721.91 |
| **2004** | March | 153,880.0 | $7,406.60 |
| **2004** | April | 195,340.0 | $9,139.86 |
| **2004** | May | 206,030.0 | $9,523.46 |
| **2004** | June | 200,840.0 | $8,939.25 |
| **2004** | July | 186,630.0 | $8,385.24 |
| **2004** | August | 193,860.0 | $8,949.17 |
| **2004** | September | 216,190.0 | $9,686.26 |
| **2004** | October | 166,930.0 | $7,744.81 |
| **2004** | November | 194,970.0 | $8,901.68 |
| **2004** | December | 131,510.0 | $6,142.46 |
| **2005** | January | 127,070.0 | $12,046.64 |
| **2005** | February | 168,930.0 | $7,966.28 |
| **2005** | March | 151,020.0 | $7,180.69 |
| **2005** | April | 157,700.0 | $7,307.02 |
| **2005** | May | 180,670.0 | $8,395.28 |
| **2005** | June | 194,500.0 | $8,712.12 |
| **2005** | July | 203,420.0 | $9,316.80 |
| **2005** | August | 207,550.0 | $9,492.74 |
| **2005** | September | 237,390.0 | $10,551.10 |
| **2005** | October | 169,720.0 | $8,057.92 |
| **2005** | November | 190,830.0 | $8,711.88 |
| **2005** | December | 143,420.0 | $6,911.75 |
| **2006** | January | 130,050.0 | $6,285.06 |
| **2006** | February | 153,340.0 | $9,017.12 |
| **2006** | March | 144,090.0 | $8,808.71 |
| **2006** | April | 179,020.0 | $10,499.41 |
| **2006** | May | 163,130.0 | $10,503.41 |
| **2006** | June | 196,340.0 | $10,180.63 |
| **2006** | July | 189,290.0 | $10,264.40 |
| **2006** | August | 238,180.0 | $12,874.04 |
| **2006** | September | 174,950.0 | $8,840.19 |
| **2006** | October | 167,480.0 | $7,633.90 |
| **2006** | November | 178,000.0 | $8,918.62 |

| | | | |
|---|---|---|---|
| **2006** | December | 151,930.0 | $7,430.72 |
| **2007** | January | 140,370.0 | $6,442.95 |
| **2007** | February | 175,670.0 | $6,769.90 |
| **2007** | March | 157,640.0 | $8,009.57 |
| **2007** | April | 176,410.0 | $8,350.42 |
| **2007** | May | 234,070.0 | $12,258.19 |
| **2007** | June | 192,300.0 | $10,769.97 |
| **2007** | July | 245,950.0 | $14,143.36 |
| **2007** | August | 233,210.0 | $12,135.88 |
| **2007** | September | 232,060.0 | $11,690.43 |
| **2007** | October | 201,930.0 | $8,586.13 |
| **2007** | November | 184,940.0 | $7,624.69 |
| **2007** | December | 160,720.0 | $6,708.44 |
| **2008** | January | 172,950.0 | $7,691.86 |
| **2008** | February | 145,730.0 | $6,365.46 |
| **2008** | March | 167,460.0 | $7,933.99 |
| **2008** | April | 198,310.0 | $11,682.33 |
| **2008** | May | 201,330.0 | $11,287.77 |
| **2008** | June | 197,290.0 | $13,104.03 |
| **2008** | July | 242,830.0 | $16,242.95 |
| **2008** | August | 214,090.0 | $17,121.79 |
| **2008** | September | 222,640.0 | $13,609.51 |
| **2008** | October | 171,290.0 | $9,511.87 |
| **2008** | November | 194,200.0 | $10,750.61 |
| **2008** | December | 138,960.0 | $6,729.77 |
| **2009** | January | 134,630.0 | $7,213.02 |
| **2009** | February | 173,840.0 | $9,910.54 |
| **2009** | March | 176,230.0 | $10,133.13 |
| **2009** | April | 167,690.0 | $10,813.76 |
| **2009** | May | 197,110.0 | $12,317.33 |
| **2009** | June | 251,390.0 | $16,271.21 |
| **2009** | July | 214,500.0 | $14,358.44 |
| **2009** | August | 211,010.0 | $14,434.09 |
| **2009** | September | 237,140.0 | $15,736.07 |
| **2009** | October | 155,510.0 | $10,119.22 |
| **2009** | November | 200,430.0 | $11,835.98 |
| **2009** | December | 131,240.0 | $7,967.57 |
| **2010** | January | 146,710.0 | $8,337.76 |
| **2010** | February | 186,840.0 | $11,623.54 |
| **2010** | March | 137,820.0 | $8,367.86 |
| **2010** | April | 205,580.0 | $13,748.96 |
| **2010** | May | 188,980.0 | $12,466.86 |
| **2010** | June | 239,570.0 | $17,691.10 |
| **2010** | July | 253,170.0 | $17,112.50 |
| **2010** | August | 233,520.0 | $16,644.56 |
| **2010** | September | 235,420.0 | $17,066.51 |
| **2010** | October | 174,150.0 | $11,206.47 |
| **2010** | November | 192,790.0 | $12,069.75 |
| **2010** | December | 126,550.0 | $7,548.69 |

| | | | |
|---|---|---|---|
| **2011** | January | 130,340.0 | $8,597.57 |
| **2011** | February | 166,320.0 | $10,636.83 |
| **2011** | March | 139,480.0 | $9,253.88 |
| **2011** | April | 155,330.0 | $10,684.87 |
| **2011** | May | 198,790.0 | $14,090.49 |
| **2011** | June | 223,640.0 | $16,546.04 |
| **2011** | July | 249,870.0 | $18,148.47 |
| **2011** | August | 184,620.0 | $13,688.00 |
| **2011** | September | 190,100.0 | $14,685.46 |
| **2011** | October | 173,090.0 | $11,834.85 |
| **2011** | November | 174,480.0 | $11,589.87 |
| **2011** | December | 123,700.0 | $7,957.96 |
| **2012** | January | 118,050.0 | $7,955.69 |
| **2012** | February | 155,020.0 | $10,359.32 |
| **2012** | March | 159,190.0 | $11,250.02 |
| **2012** | April | 176,480.0 | $13,210.57 |
| **2012** | May | 221,470.0 | $16,727.22 |
| **2012** | June | 173,290.0 | $14,365.77 |
| **2012** | July | 236,570.0 | $17,270.09 |
| **2012** | August | 219,510.0 | $16,965.22 |
| **2012** | September | 189,370.0 | $15,125.15 |
| **2012** | October | 174,990.0 | $13,138.77 |
| **2012** | November | 189,233.0 | $13,208.46 |
| **2012** | December | 127,163.0 | $9,410.06 |
| **2013** | January | 167,030.0 | $12,133.99 |
| **2013** | February | 1,160,080.0 | $85,559.27 |
| **2013** | March | 13,250.0 | $969.48 |
| **2013** | April | 0.0 | $0.00 |
| **2013** | May | 33,230.0 | $2,490.54 |
| **2013** | June | 21,160.0 | $1,707.04 |

**Eaton Hall Steam Usage**

| YEAR | MONTH | STEAM | STEAM COST | STEAM COST PER UNIT |
|---|---|---|---|---|
| **2003** | August | | | |
| **2003** | September | 40,500.0 | $2,151.76 | 0.053129877 |
| **2003** | October | 107,200.0 | $5,275.83 | 0.049214832 |
| **2003** | November | 112,500.0 | $9,470.43 | 0.0841816 |
| **2003** | December | 98,900.0 | $8,676.83 | 0.087733367 |
| **2004** | January | 121,800.0 | $10,817.34 | 0.088812315 |
| **2004** | February | 135,300.0 | $11,797.73 | 0.087196822 |
| **2004** | March | 148,200.0 | $13,059.77 | 0.088122605 |
| **2004** | April | 93,700.0 | $8,245.99 | 0.088004162 |
| **2004** | May | 106,800.0 | $9,985.09 | 0.093493352 |
| **2004** | June | 84,700.0 | $7,810.76 | 0.092216765 |
| **2004** | July | 95,900.0 | $8,620.10 | 0.08988634 |
| **2004** | August | 99,000.0 | $8,922.19 | 0.090123131 |
| **2004** | September | 118,400.0 | $10,093.77 | 0.085251436 |
| **2004** | October | 110,300.0 | $9,496.23 | 0.08609456 |
| **2004** | November | 112,600.0 | $12,088.90 | 0.107361456 |
| **2004** | December | 104,400.0 | $10,080.99 | 0.096561207 |
| **2005** | January | 135,000.0 | $13,512.92 | 0.100095704 |
| **2005** | February | 146,200.0 | $14,100.33 | 0.096445486 |
| **2005** | March | 97,800.0 | $8,906.00 | 0.091063395 |
| **2005** | April | 115,500.0 | $11,961.29 | 0.103560952 |
| **2005** | May | 128,100.0 | $12,754.12 | 0.099563778 |
| **2005** | June | 111,200.0 | $10,739.86 | 0.096581475 |
| **2005** | July | 84,600.0 | $8,558.32 | 0.101162175 |
| **2005** | August | 93,100.0 | $9,585.64 | 0.102960687 |
| **2005** | September | 85,300.0 | $9,627.26 | 0.11286354 |
| **2005** | October | 80,000.0 | $10,167.36 | 0.127092 |
| **2005** | November | 86,600.0 | $10,181.78 | 0.117572517 |
| **2005** | December | 99,300.0 | $11,723.97 | 0.118066163 |
| **2006** | January | 81,200.0 | $9,153.89 | 0.112732635 |
| **2006** | February | 89,400.0 | $9,918.04 | 0.110940045 |
| **2006** | March | 86,100.0 | $9,540.89 | 0.110811731 |
| **2006** | April | 67,000.0 | $6,423.64 | 0.095875224 |
| **2006** | May | 57,200.0 | $5,427.89 | 0.094893182 |
| **2006** | June | 49,000.0 | $4,506.88 | 0.091977143 |
| **2006** | July | 52,100.0 | $4,891.04 | 0.093877927 |
| **2006** | August | 49,900.0 | $4,912.04 | 0.098437675 |
| **2006** | September | 42,300.0 | $4,091.73 | 0.096731206 |
| **2006** | October | 39,900.0 | $3,301.58 | 0.082746366 |
| **2006** | November | 46,000.0 | $4,917.38 | 0.106899565 |
| **2006** | December | 54,700.0 | $5,979.49 | 0.10931426 |

| | | | | |
|---|---|---|---|---|
| **2007** | January | 61,200.0 | $6,370.92 | 0.1041 |
| **2007** | February | 41,000.0 | $4,673.12 | 0.113978537 |
| **2007** | March | 17,800.0 | $1,914.77 | 0.107571348 |
| **2007** | April | 25,500.0 | $2,411.68 | 0.094575686 |
| **2007** | May | 15,400.0 | $1,552.51 | 0.100812338 |
| **2007** | June | 14,100.0 | $1,495.04 | 0.106031106 |
| **2007** | July | 13,300.0 | $1,345.73 | 0.101183045 |
| **2007** | August | 17,600.0 | $1,611.88 | 0.09158433 |
| **2007** | September | 24,700.0 | $2,241.64 | 0.09075466 |
| **2007** | October | 39,800.0 | $3,669.82 | 0.092206653 |
| **2007** | November | 44,200.0 | $4,141.80 | 0.093705984 |
| **2007** | December | 66,500.0 | $6,336.40 | 0.09528414 |
| **2008** | January | 70,100.0 | $6,744.32 | 0.096210017 |
| **2008** | February | 77,600.0 | $7,956.32 | 0.102529849 |
| **2008** | March | 62,800.0 | $6,563.72 | 0.104517807 |
| **2008** | April | 63,200.0 | $6,937.17 | 0.109765375 |
| **2008** | May | 75,900.0 | $9,096.95 | 0.119854448 |
| **2008** | June | 84,000.0 | $10,236.14 | 0.121858799 |
| **2008** | July | 100,500.0 | $13,234.66 | 0.131688193 |
| **2008** | August | 86,000.0 | $9,454.70 | 0.109938407 |
| **2008** | September | 72,200.0 | $7,662.66 | 0.106131028 |
| **2008** | October | 90,000.0 | $9,050.41 | 0.100560057 |
| **2008** | November | 116,500.0 | $11,659.89 | 0.100084889 |
| **2008** | December | 109,600.0 | $11,736.77 | 0.107087304 |
| **2009** | January | 136,300.0 | $15,396.76 | 0.112962318 |
| **2009** | February | 129,600.0 | $13,909.17 | 0.107323863 |
| **2009** | March | 148,200.0 | $15,503.31 | 0.104610711 |
| **2009** | April | 119,700.0 | $13,444.99 | 0.11232241 |
| **2009** | May | 114,300.0 | $11,555.87 | 0.101101242 |
| **2009** | June | 112,500.0 | $11,936.33 | 0.106100739 |
| **2009** | July | 94,200.0 | $9,711.13 | 0.10309054 |
| **2009** | August | 71,300.0 | $7,170.85 | 0.100572989 |
| **2009** | September | 74,200.0 | $6,451.31 | 0.086944912 |
| **2009** | October | 56,300.0 | $4,764.30 | 0.084623414 |
| **2009** | November | 96,800.0 | $9,373.86 | 0.096837407 |
| **2009** | December | 114,400.0 | $11,018.44 | 0.096315033 |
| **2010** | January | 119,300.0 | $11,245.83 | 0.094265136 |
| **2010** | February | 164,700.0 | $15,602.72 | 0.094734174 |
| **2010** | March | 113,000.0 | $10,644.09 | 0.094195496 |
| **2010** | April | 119,300.0 | $9,660.78 | 0.08097884 |
| **2010** | May | 120,200.0 | $9,731.79 | 0.080963287 |
| **2010** | June | 114,100.0 | $9,433.50 | 0.082677442 |
| **2010** | July | 96,500.0 | $7,885.80 | 0.081718148 |
| **2010** | August | 93,000.0 | $7,516.74 | 0.080825161 |
| **2010** | September | 91,500.0 | $7,387.94 | 0.080742514 |
| **2010** | October | 23,400.0 | $1,957.27 | 0.083644077 |
| **2010** | November | 35,900.0 | $3,035.46 | 0.084553148 |
| **2010** | December | 44,000.0 | $3,686.05 | 0.083773757 |
| **2011** | January | 65,100.0 | $5,488.00 | 0.084301057 |

| | | | | |
|---|---|---|---|---|
| **2011** | February | 87,800.0 | $7,298.95 | 0.08313156 |
| **2011** | March | 28,900.0 | $2,482.82 | 0.085910886 |
| **2011** | April | 24,300.0 | $1,853.07 | 0.076258218 |
| **2011** | May | 23,200.0 | $1,781.33 | 0.076781401 |
| **2011** | June | 22,000.0 | $1,691.33 | 0.076878827 |
| **2011** | July | 23,900.0 | $1,847.09 | 0.077283983 |
| **2011** | August | 19,000.0 | $1,443.93 | 0.075996153 |
| **2011** | September | 27,200.0 | $2,098.71 | 0.077158493 |
| **2011** | October | 28,700.0 | $2,224.37 | 0.077504157 |
| **2011** | November | 36,640.0 | $2,839.60 | 0.0775 |
| **2011** | December | 54,960.0 | $4,056.05 | 0.073800036 |
| **2012** | January | 28,700.0 | $2,200.63 | 0.076676875 |
| **2012** | February | 37,200.0 | $2,807.94 | 0.075482258 |
| **2012** | March | 31,700.0 | $2,416.57 | 0.076232407 |
| **2012** | April | 34,900.0 | $2,603.06 | 0.074586132 |
| **2012** | May | 31,900.0 | $2,402.54 | 0.075314674 |
| **2012** | June | 22,400.0 | $1,633.55 | 0.072926536 |
| **2012** | July | 22,700.0 | $1,718.73 | 0.075715035 |
| **2012** | August | 26,200.0 | $1,933.19 | 0.073785889 |
| **2012** | September | 27,200.0 | $1,996.70 | 0.07340804 |
| **2012** | October | 29,700.0 | $2,176.87 | 0.073295145 |
| **2012** | November | 44,900.0 | $3,157.66 | 0.070326526 |
| **2012** | December | 52,700.0 | $3,807.62 | 0.07225077 |
| **2013** | January | 48,400.0 | $3,396.69 | 0.070179616 |
| **2013** | February | 55,500.0 | $3,961.29 | 0.07137462 |
| **2013** | March | 42,000.0 | $2,926.60 | 0.069680871 |
| **2013** | April | 42,800.0 | $3,205.34 | 0.074891037 |
| **2013** | May | 30,400.0 | $2,427.26 | 0.079844224 |
| **2013** | June | 28,100.0 | $2,234.66 | 0.079525313 |

## Monthly Electrical Use Table

| | MONTHLY AVERAGE | EXCESS OF WINTER MONTHLY AVERAGE | BASE MONTHLY USAGE | CLASS DAYS | BASELINE CLASS USAGE | BASE USAGE TOTAL | EXCESS |
|---|---|---|---|---|---|---|---|
| **JAN** | 139,924.4 | 732.3 | 126,666.0 | 18 | 13248 | 139,914 | 10.44 |
| **FEB** | 163,118.9 | 23,926.74 | 114,408.0 | 28 | 20608 | 135,016 | 28,102.89 |
| **MAR** | 154,090.0 | 14,897.85 | 126,666.0 | 22 | 16192 | 142,858 | 0.00 |
| **APR** | 181,770.0 | 42,577.85 | 122,580.0 | 3 | 2208 | 124,788 | 56,982.00 |
| **MAY** | 182,682.2 | 43,490.1 | 126,666.0 | 15 | 11040 | 137,706 | 44,976.22 |
| **JUN** | 188,424.4 | 49,232.3 | 122,580.0 | 10 | 7360 | 129,940 | 58,484.44 |
| **JUL** | 227,351.3 | 88,159.1 | 126,666.0 | 12 | 8832 | 135,498 | 91,853.25 |
| **AUG** | 216,000.0 | 76,807.9 | 126,666.0 | 6 | 4416 | 131,082 | 84,918.00 |
| **SEP** | 212,233.8 | 73,041.6 | 122,580.0 | 30 | 22080 | 144,660 | 67,573.75 |
| **OCT** | 172,787.8 | 33,595.6 | 126,666.0 | 27 | 19872 | 146,538 | 26,249.78 |
| **NOV** | 188,874.8 | 49,682.6 | 122,580.0 | 26 | 19136 | 141,716 | 47,158.78 |
| **DEC** | 140,660.3 | 1,468.2 | 126,666.0 | 19 | 13984 | 140,650 | 10.33 |

**Eaton Hall Baseline Steam Table**

**Eaton Electrical Degradation Calculation (0.008292)**

| | | | |
|---|---|---|---|
| | | Coeff | 0.008292 |
| | | | |
| | Year | kWh Base | |
| 2012 | | 663,563 | 0 |
| 2013 | 1 | 669,111 | 5,548 |
| 2014 | 2 | 674,706 | 11,143 |
| 2015 | 3 | 680,347 | 16,784 |
| 2016 | 4 | 686,036 | 22,473 |
| 2017 | 5 | 691,772 | 28,209 |
| 2018 | 6 | 697,556 | 33,993 |
| 2019 | 7 | 703,389 | 39,826 |
| 2020 | 8 | 709,270 | 45,707 |
| 2021 | 9 | 715,201 | 51,638 |
| 2022 | 10 | 721,181 | 57,618 |
| 2023 | 11 | 727,211 | 63,648 |
| 2024 | 12 | 733,291 | 69,728 |
| 2025 | 13 | 739,422 | 75,859 |
| 2026 | 14 | 745,605 | 82,042 |
| 2027 | 15 | 751,839 | 88,276 |
| 2028 | 16 | 758,125 | 94,562 |
| 2029 | 17 | 764,464 | 100,901 |
| 2030 | 18 | 770,856 | 107,293 |
| 2031 | 19 | 777,302 | 113,739 |
| 2032 | 20 | 783,801 | 120,238 |
| | 21 | 790,355 | 126,792 |
| | Total | 15,290,840 | 1,356,017 |

## Eaton Electrical Degradation Calculation (0.01)

| | | | |
|---|---|---|---|
| | | Coeff | 0.01 |
| | | | |
| | Year | kWh Base | |
| 2012 | | 663,563 | 0 |
| 2013 | 1 | 670,266 | 6,703 |
| 2014 | 2 | 677,036 | 13,473 |
| 2015 | 3 | 683,875 | 20,312 |
| 2016 | 4 | 690,783 | 27,220 |
| 2017 | 5 | 697,760 | 34,197 |
| 2018 | 6 | 704,808 | 41,245 |
| 2019 | 7 | 711,928 | 48,365 |
| 2020 | 8 | 719,119 | 55,556 |
| 2021 | 9 | 726,383 | 62,820 |
| 2022 | 10 | 733,720 | 70,157 |
| 2023 | 11 | 741,131 | 77,568 |
| 2024 | 12 | 748,617 | 85,054 |
| 2025 | 13 | 756,179 | 92,616 |
| 2026 | 14 | 763,817 | 100,254 |
| 2027 | 15 | 771,533 | 107,970 |
| 2028 | 16 | 779,326 | 115,763 |
| 2029 | 17 | 787,198 | 123,635 |
| 2030 | 18 | 795,149 | 131,586 |
| 2031 | 19 | 803,181 | 139,618 |
| 2032 | 20 | 811,294 | 147,731 |
| | 21 | 819,489 | 155,926 |
| | Total | 15,592,590 | 1,657,767 |

## Eaton Electrical Degradation Calculation (0.02)

| | | | |
|---|---|---|---|
| | | Coeff | 0.02 |
| | | | |
| | Year | kWh Base | |
| 2012 | | 663,563 | 0 |
| 2013 | 1 | 677,105 | 13,542 |
| 2014 | 2 | 690,924 | 27,361 |
| 2015 | 3 | 705,024 | 41,461 |
| 2016 | 4 | 719,412 | 55,849 |
| 2017 | 5 | 734,094 | 70,531 |
| 2018 | 6 | 749,076 | 85,513 |
| 2019 | 7 | 764,363 | 100,800 |
| 2020 | 8 | 779,962 | 116,399 |
| 2021 | 9 | 795,880 | 132,317 |
| 2022 | 10 | 812,122 | 148,559 |
| 2023 | 11 | 828,696 | 165,133 |
| 2024 | 12 | 845,608 | 182,045 |
| 2025 | 13 | 862,866 | 199,303 |
| 2026 | 14 | 880,475 | 216,912 |
| 2027 | 15 | 898,444 | 234,881 |
| 2028 | 16 | 916,780 | 253,217 |
| 2029 | 17 | 935,489 | 271,926 |
| 2030 | 18 | 954,581 | 291,018 |
| 2031 | 19 | 974,062 | 310,499 |
| 2032 | 20 | 993,941 | 330,378 |
| | 21 | 1,014,226 | 350,663 |
| | Total | 17,533,130 | 3,598,307 |

**Eaton Electrical Degradation Sliding Coeff.**

| | Year | kWh Base | Additional | coeff |
|---|---|---|---|---|
| 2012 | | 663,563 | 0 | |
| 2013 | 1 | 669,111 | 5,548 | 0.008292 |
| 2014 | 2 | 675,503 | 11,940 | 0.008877 |
| 2015 | 3 | 682,763 | 19,200 | 0.009463 |
| 2016 | 4 | 690,917 | 27,354 | 0.010048 |
| 2017 | 5 | 699,997 | 36,434 | 0.010634 |
| 2018 | 6 | 710,038 | 46,475 | 0.011219 |
| 2019 | 7 | 721,077 | 57,514 | 0.011804 |
| 2020 | 8 | 733,158 | 69,595 | 0.01239 |
| 2021 | 9 | 746,328 | 82,765 | 0.012975 |
| 2022 | 10 | 760,638 | 97,075 | 0.013561 |
| 2023 | 11 | 776,146 | 112,583 | 0.014146 |
| 2024 | 12 | 792,915 | 129,352 | 0.014731 |
| 2025 | 13 | 811,012 | 147,449 | 0.015317 |
| 2026 | 14 | 830,513 | 166,950 | 0.015902 |
| 2027 | 15 | 851,500 | 187,937 | 0.016488 |
| 2028 | 16 | 874,061 | 210,498 | 0.017073 |
| 2029 | 17 | 898,295 | 234,732 | 0.017658 |
| 2030 | 18 | 924,307 | 260,744 | 0.018244 |
| 2031 | 19 | 952,214 | 288,651 | 0.018829 |
| 2032 | 20 | 982,141 | 318,578 | 0.019415 |
| | 21 | 1,014,226 | 350,663 | 0.02 |
| | | 16,796,860 | 2,862,037 | |

## Eaton Steam Degradation Calculation (0.005)

| | | | |
|---|---|---|---|
| | | Coeff | 0.005 |
| | | | |
| | Year | kWh Base | |
| 2012 | | 1,033,556 | 0 |
| 2013 | 1 | 1,038,750 | 5,194 |
| 2014 | 2 | 1,043,970 | 10,414 |
| 2015 | 3 | 1,049,216 | 15,660 |
| 2016 | 4 | 1,054,488 | 20,932 |
| 2017 | 5 | 1,059,787 | 26,231 |
| 2018 | 6 | 1,065,113 | 31,557 |
| 2019 | 7 | 1,070,465 | 36,909 |
| 2020 | 8 | 1,075,844 | 42,288 |
| 2021 | 9 | 1,081,250 | 47,694 |
| 2022 | 10 | 1,086,684 | 53,128 |
| 2023 | 11 | 1,092,145 | 58,589 |
| 2024 | 12 | 1,097,633 | 64,077 |
| 2025 | 13 | 1,103,148 | 69,592 |
| 2026 | 14 | 1,108,692 | 75,136 |
| 2027 | 15 | 1,114,263 | 80,707 |
| 2028 | 16 | 1,119,863 | 86,307 |
| 2029 | 17 | 1,125,490 | 91,934 |
| 2030 | 18 | 1,131,146 | 97,590 |
| 2031 | 19 | 1,136,830 | 103,274 |
| 2032 | 20 | 1,142,543 | 108,987 |
| | 21 | 1,148,284 | 114,728 |
| | Total | 22,945,602 | 1,240,926 |

**Eaton Steam Degradation Calculation (0.015)**

| | | | |
|---|---|---|---|
| | | Coeff | 0.015 |
| | | | |
| | Year | kWh Base | |
| 2012 | | 1,033,556 | 0 |
| 2013 | 1 | 1,049,295 | 15,739 |
| 2014 | 2 | 1,065,275 | 31,719 |
| 2015 | 3 | 1,081,497 | 47,941 |
| 2016 | 4 | 1,097,967 | 64,411 |
| 2017 | 5 | 1,114,687 | 81,131 |
| 2018 | 6 | 1,131,662 | 98,106 |
| 2019 | 7 | 1,148,895 | 115,339 |
| 2020 | 8 | 1,166,391 | 132,835 |
| 2021 | 9 | 1,184,153 | 150,597 |
| 2022 | 10 | 1,202,186 | 168,630 |
| 2023 | 11 | 1,220,494 | 186,938 |
| 2024 | 12 | 1,239,080 | 205,524 |
| 2025 | 13 | 1,257,949 | 224,393 |
| 2026 | 14 | 1,277,106 | 243,550 |
| 2027 | 15 | 1,296,554 | 262,998 |
| 2028 | 16 | 1,316,298 | 282,742 |
| 2029 | 17 | 1,336,343 | 302,787 |
| 2030 | 18 | 1,356,694 | 323,138 |
| 2031 | 19 | 1,377,354 | 343,798 |
| 2032 | 20 | 1,398,329 | 364,773 |
| | 21 | 1,419,623 | 386,067 |
| | Total | 25,737,832 | 4,033,156 |

**Eaton Steam Degradation Calculation Sliding**

| | Year | kWh Base | | |
|---|---|---|---|---|
| 2012 | | 1,033,556 | 0 | |
| 2013 | 1 | 1,038,750 | 5,194 | 0.005 |
| 2014 | 2 | 1,045,020 | 11,464 | 0.0055 |
| 2015 | 3 | 1,052,386 | 18,830 | 0.006 |
| 2016 | 4 | 1,060,871 | 27,315 | 0.0065 |
| 2017 | 5 | 1,070,503 | 36,947 | 0.007 |
| 2018 | 6 | 1,081,312 | 47,756 | 0.0075 |
| 2019 | 7 | 1,093,333 | 59,777 | 0.008 |
| 2020 | 8 | 1,106,604 | 73,048 | 0.0085 |
| 2021 | 9 | 1,121,169 | 87,613 | 0.009 |
| 2022 | 10 | 1,137,075 | 103,519 | 0.0095 |
| 2023 | 11 | 1,154,375 | 120,819 | 0.01 |
| 2024 | 12 | 1,173,125 | 139,569 | 0.0105 |
| 2025 | 13 | 1,193,390 | 159,834 | 0.011 |
| 2026 | 14 | 1,215,236 | 181,680 | 0.0115 |
| 2027 | 15 | 1,238,739 | 205,183 | 0.012 |
| 2028 | 16 | 1,263,980 | 230,424 | 0.0125 |
| 2029 | 17 | 1,291,048 | 257,492 | 0.013 |
| 2030 | 18 | 1,320,038 | 286,482 | 0.0135 |
| 2031 | 19 | 1,351,054 | 317,498 | 0.014 |
| 2032 | 20 | 1,384,208 | 350,652 | 0.0145 |
| | 21 | 1,419,623 | 386,067 | 0.015 |
| | | 24,811,838 | 3,107,162 | |

## $M^2$SEC Embodied Energy Tables

| Description | Quantity | Unit | Conversion | Density | Kg | ICE | MJ |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Excavation | | | | | | | |
| Drilled Piers, 40' Long | 1300.816 | CY | 0.764555 | 2300 | 2287454 | 0.75 | 1715590 |
| Haul Pier Spoils | 1300.816 | CY | 0.764555 | 2300 | 2287454 | 0.75 | 1715590 |
| Grade Beam & Ftg Excavate | 742 | CY | 0.764555 | 2300 | 1304789 | 0.75 | 978592 |
| Crushed Rock @ SOG, 18" Thick | 1025.167 | CY | 0.764555 | 1224.7 | 959915.2 | 0.083 | 79672.96 |
| Granular Backfill | 2656.593 | CY | 0.764555 | 1224.7 | 2487501 | 0.083 | 206462.6 |
| Perimeter Foundation Drains | 839.3468 | LF | 0.308443 | | 258.8905 | 67.5 | 17475.11 |
| | | | | | | | |
| | | | | | | Total | 4713384 |
| | | | | | | | |
| Building Structure | | | | | | | |
| Drilled Pier Concrete | 1548.413 | CY | 0.764555 | 2300 | 2722847 | 0.75 | 2042135 |
| Pier Caps | 216 | CY | 0.764555 | 2300 | 379830.9 | 0.75 | 284873.1 |
| Tie Beams | 160 | CY | 0.764555 | 2300 | 281356.2 | 0.75 | 211017.1 |
| Grade Beams; 2'x3', Form 100% | 366 | CY | 0.764555 | 2300 | 643602.3 | 0.75 | 482701.7 |
| Elevator Pit Walls | 200 | SF | 3.775571 | 2300 | 8683.813 | 0.75 | 6512.859 |
| Foundation Walls & Pilasters | 9692.625 | SF | 251.6022 | 2300 | 578685.1 | 0.75 | 434013.9 |
| Fdn Wall 24" premium | 1092 | SF | 0.509652 | 2300 | 1172.2 | 0.75 | 879.1502 |
| Slab on Grade - 6" | 12748 | SF | 0.127421 | 2300 | 293.0676 | 0.75 | 219.8007 |
| Slab on Grade - 4" | 5705 | SF | 0.08495 | 2300 | 195.386 | 0.75 | 146.5395 |
| 7" Slab Premium | 2509 | SF | 0.148663 | 2300 | 341.9251 | 0.75 | 256.4439 |
| Floor Trench @ Lab, 18"x18" | 87 | LF | 0.191139 | 2300 | 38246.86 | 0.75 | 28685.14 |
| Isolation Slab Premium | 1381 | SF | 37.5 | 0.453592 | 23490.4 | 0.75 | 17617.8 |
| Concrete Columns | 292.2408 | CY | 0.764555 | 2300 | 513898.4 | 0.75 | 385423.8 |
| HVAC Penthouse Roof Framing | 29 | TN | N/A | 907.185 | 26308.37 | 20.1 | 528798.1 |
| Anechoic Chamber Steel | 6 | TN | N/A | 907.185 | 5443.11 | 20.1 | 109406.5 |
| Lightwell Framing | 1.488 | TN | N/A | 907.185 | 1349.891 | 20.1 | 27132.81 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Greenscreen Framing | 3.2025 | TN | N/A | 907.185 | 2905.26 | 20.1 | 58395.73 |
| 1.5" Type B Steel Roof Deck | 5991.3 | SF | 2.7 | 0.453592 | 7337.536 | 20.1 | 147484.5 |
| 2 EA Exit Stairs, 4.00' Wide | 46 | VF | 13.16 | 5858.242 | 5858.242 | 20.1 | 117750.7 |
| 1 EA Bsmt Stairs, 4.00' Wide | 16 | VF | 4.5 | 2003.198 | 2003.198 | 20.1 | 40264.29 |
| Roof Egress Stair | 16 | VF | 4.5 | 2003.198 | 2003.198 | 20.1 | 40264.29 |
| Stair Railings, Mesh Panel Style | 125.1429 | LF | 4 | 0.453592 | 227.0552 | 20.1 | 4563.809 |
| Ext Stair Railings, Mesh Panel Style | 84.42857 | LF | 4 | 0.453592 | 153.1845 | 20.1 | 3079.008 |
| Wall Railings | 195.1429 | LF | 2 | 0.453592 | 177.0305 | 20.1 | 3558.313 |
| Ornamental Metal Railing | 59 | LF | 4 | 0.453592 | 107.0477 | 20.1 | 2151.659 |
| Suspended Masonry Supports | 252.042 | LF | 20 | 0.453592 | 2286.485 | 22.6 | 51674.55 |
| Masonry Lintels or Shelf Angles | 250.2702 | LF | 20 | 0.453592 | 2270.411 | 22.6 | 51311.29 |
| Curtainwall Support Steel, 5#/SF | 182.3183 | SF | 5 | 0.453592 | 413.4907 | 20.1 | 8311.162 |
| Phase Change Wall Supports | 2368 | SF | | | 0 | 20.1 | 0 |
| Lab Equipment Supports | 11 | EA | | | 0 | 20.1 | 0 |
| Expansion Joint Covers | 330 | LF | 0.0083 | 0.453592 | 1.242388 | 20.1 | 24.97201 |
| Dock Stair & Railing, HD Galv | 1 | EA | | | 0 | 20.1 | 0 |
| Other Miscellaneous Steel | 3.5145 | TN | X | 907.185 | 3188.302 | 20.1 | 64084.86 |
| Housekeeping Pads, Etc | 1366.8 | SF | 0.382277 | 2300 | 1201743 | 0.75 | 901307 |
| Equipment Foundations | 713 | SF | 0.382277 | 2300 | 626896.8 | 0.75 | 470172.6 |
| Pan Stair Fill | 784.8016 | SF | 0.127426 | 2300 | 230009.2 | 0.75 | 172506.9 |
| Penthouse & Misc Curbs | 357 | LF | 37.5 | 0.453592 | 6072.463 | 0.75 | 4554.347 |
| | | | | | | | |
| | | | | | | Total | 6701280 |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Strongwall & Dyno Base | | | | | | | |
| Strongwall Piers EX | 10.47197 | CY | 0.764555 | 2300 | 18414.7 | 0.75 | 13811.03 |
| Strongwall Piers Haul Spoils | 10.47197 | CY | 0.764555 | 2300 | 18414.7 | 0.75 | 13811.03 |
| Strongwall Piers | 12.56636 | SF | 300 | 0.453592 | 1710 | 0.75 | 1282.5 |
| Strongwall | 500.5 | SF | 300 | 0.453592 | 68106.84 | 0.75 | 51080.13 |
| Strongwall Base | 54 | CY | 0.764555 | 2300 | 94957.71 | 0.75 | 71218.29 |
| Dyno Base | 9 | CY | 0.764555 | 2300 | 15826.29 | 0.75 | 11869.71 |
| Strongwall Lid | 485 | SF | 300 | 0.453592 | 65997.64 | 0.75 | 49498.23 |
| Strongwall Column | 7.469136 | CY | 0.764555 | 2300 | 13134.3 | 0.75 | 9850.723 |
| | | | | | | | |
| | | | | | | Total | 222421.6 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | Total | 6923702 |
| | | | | | | | |
| Building Skin | | | | | | | |
| Brick Veneer | 7784 | SF | 332065.4 | 0.453592 | 150622.2 | 3 | 451866.7 |
| Precast Panels Veneer | 5381 | SF | 206271.7 | 0.453592 | 93563.18 | 0.75 | 70172.38 |
| Metal Wall Panels Accent | 1407 | SF | 1685.469 | 0.453592 | 764.5151 | 0.75 | 573.3864 |
| Modular Brick and 8'' CMU | 2728 | SF | 103726.2 | 0.453592 | 47049.39 | 0.67 | 31523.09 |
| Metal Wall Panels at Penthouse | 4757 | SF | 5698.49 | 0.453592 | 2584.789 | 0.75 | 1938.592 |
| HVAC Louvers | 283 | SF | 339.0104 | 0.453592 | 153.7724 | 0.75 | 115.3293 |
| Sheet Metal Soffits,Flat | 479 | SF | 573.8021 | 0.453592 | 260.272 | 0.75 | 195.204 |
| | | | | | | | |
| | | | | | | Total | 556384.7 |
| | | | | | | | |
| Interior Masonry | | | | | | | |
| 8" CMU Partitions - Reverb | 3532 | SF | 134296.6 | 0.453592 | 60915.85 | 0.67 | 40813.62 |
| 8" CMU Partitions | 11482 | SF | 436577.9 | 0.453592 | 198028.3 | 0.67 | 132678.9 |
| Ground Face CMU Premium | 4191 | SF | 159353.6 | 0.453592 | 72281.52 | 0.67 | 48428.62 |
| | | | | | | | |
| | | | | | | Total | 221921.2 |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | Total | 778305.8 |
| | | | | | | | |
| Rough Carpentry | | | | | | | |
| Plywood at Parapet | 2714.252 | SF | 2 | 0.453592 | 2462.326 | 15 | 36934.89 |
| | | | | | | | |
| | | | | | | Total | 36934.89 |
| | | | | | | | |
| Finish Carpentry and Millwork | | | | | | | |
| Corian (Top Only) Vanities | 24 | LF | 8.066667 | 0.453592 | 87.81541 | 83.1 | 7297.461 |
| 6" Wood Base, One Piece | 134 | LF | 5.5 | 0.453592 | 334.2973 | 15 | 5014.46 |
| Corian Window Sills, 8" Avg Width | 279 | LF | 2.933333 | 0.453592 | 371.2197 | 2.54 | 942.898 |
| Closet Shelving | 90 | LF | 5.5 | 0.453592 | 224.528 | 15 | 3367.921 |
| Plastic Laminate Base Cabinets | 41 | LF | 7 | 0.453592 | 130.1809 | 9.5 | 1236.719 |
| Plastic Laminate Countertops | 124 | LF | 7 | 0.453592 | 393.7179 | 9.5 | 3740.32 |
| Plastic Laminate Upper Cabinets | 43 | LF | 7 | 0.453592 | 136.5312 | 9.5 | 1297.046 |
| MAP Wall Panel System | 244 | SF | 6 | 0.453592 | 664.0587 | 155 | 102929.1 |
| SS Wall Panels @ Emerg Eyewash | 123 | SF | 4 | 0.453592 | 223.1673 | 155 | 34590.93 |
| Cement Board Panels | 736 | SF | 3 | 0.453592 | 1001.531 | 10.4 | 10415.92 |
| | | | | | | | |
| | | | | | | Total | 170832.8 |
| | | | | | | | |
| | | | | | | Total | 207767.7 |
| | | | | | | | |
| | | | | | | | |
| Membrane Roofing | | | | | | | |
| TPO Fully Adhered Membrane | 20760 | SF | 12 | 0.453592 | 112998.8 | 77.2 | 8723510 |
| Densdeck Insulation Cover Board | 17769 | SF | 1.7 | 0.453592 | 13701.79 | 2 | 27403.58 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Roof Crickets, Interior | 888.45 | SF | 122.675 | 0.453592 | 49437.27 | 26.2 | 1295256 |
| Tapered Insulation Prem | 15992.1 | SF | 0.324 | 0.453592 | 2350.26 | 91 | 213873.7 |
| Roof Walkway Pads | 600 | SF | 1.3 | 0.453592 | 353.8018 | 91 | 32195.96 |
| Parapet Flashing | 2714.252 | SF | 61.3375 | 0.453592 | 75516.47 | 26.2 | 1978531 |
| | | | | | | | |
| | | | | | | Total | 12270771 |
| | | | | | | | |
| Sheet Metal and Louvers | | | | | | | |
| Sheet Metal Flashings | 2071.126 | LF | 0.816213 | 0.453592 | 766.7878 | 154 | 118085.3 |
| Gutters & Downspouts | 60 | LF | 0.377358 | 0.453592 | 10.26999 | 154 | 1581.579 |
| Painted Standing Seam Roof | 200 | SF | 1.5 | 0.453592 | 136.0776 | 18.8 | 2558.259 |
| Nail Base & Insulation, R20 | 200 | SF | 2 | 0.453592 | 181.4368 | 45 | 8164.656 |
| Sheet Metal Sunscreen, Hor | 56 | LF | 1.703819 | 0.453592 | 43.27898 | 154 | 6664.962 |
| Sheet Metal Sunscreen,Vert | 168 | LF | 1.703819 | 0.453592 | 129.8369 | 154 | 19994.89 |
| | | | | | | | |
| | | | | | | Total | 157049.7 |
| | | | | | | | |
| Caulking and Waterproofing | | | | | | | |
| Spray Foam Insulation & Flashing | 22536 | SF | 0.5 | 0.453592 | 5111.075 | 20 | 102221.5 |
| Building Skin & Window Caulking | 7169.426 | LF | 0.01484 | 0.453592 | 48.2596 | 20 | 965.1919 |
| Caulk CMU Control Joints | 620.5778 | LF | 0.01484 | 0.453592 | 4.177299 | 20 | 83.54598 |
| Caulk HM Frames at CMU | 450.92 | LF | 0.01484 | 0.453592 | 3.03528 | 20 | 60.7056 |
| Dampproof Elevator Pits | 200 | SF | 0.027778 | 0.453592 | 2.519948 | 99.2 | 249.9789 |
| Waterproof/Drain Mat at Fdn Walls | 9692.625 | SF | 0.027778 | 0.453592 | 122.1246 | 99.2 | 12114.76 |
| | | | | | | | |
| | | | | | | Total | 115695.7 |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | Total | 12543517 |
| | | | | | | | |
| Doors, Frames and Hardware | | | | | | | |
| Hollow Metal Frames | 92 | EA | 41 | 0.453592 | 1710.949 | 20.1 | 34390.08 |
| HM SL/BL Frames, 36 SF/EA | 32.4 | EA | 41 | 0.453592 | 602.5516 | 20.1 | 12111.29 |
| Hollow Metal Doors | 32 | EA | 80.5 | 0.453592 | 1168.453 | 20.1 | 23485.91 |
| Solid Core Wood Doors, Oak, 7' | 81 | EA | 61.25 | 0.453592 | 2250.383 | 12 | 27004.6 |
| 42" Lab Door Premium | 37.8 | EA | 112.7 | 0.453592 | 1932.329 | 20.1 | 38839.82 |
| Stair Exit Doors 3.00' Wide | 5 | EA | 96.6 | 0.453592 | 219.0849 | 20.1 | 4403.607 |
| Finish Hardware, Cylinder Locks | 113 | EA | 6 | 0.453592 | 307.5354 | 154 | 47360.45 |
| Unload & Distribute Dr, Frame, Hdwe | 108 | EA | 0.190476 | 0.453592 | 9.331035 | 164 | 1530.29 |
| Sound Door @ Test Cell | 1 | EA | 275.35 | 0.453592 | 124.8966 | 1.352 | 168.8189 |
| Double 5' Leaf Door | 1 | EA | 613.375 | 0.453592 | 278.222 | 20.1 | 5592.262 |
| | | | | | | | |
| | | | | | | Total | 194887.1 |
| | | | | | | | |
| Glass and Glazing Systems | | | | | | | |
| Curtainwall | 2279 | SF | 104 | 0.453592 | 107508.6 | 15 | 1612628 |
| Window Wall and Storefront | 221 | SF | 104 | 0.453592 | 10425.36 | 15 | 156380.4 |
| Ribbon Windows | 951 | SF | 52 | 0.453592 | 22431.03 | 15 | 336465.5 |
| Punch Windows | 373 | SF | 52 | 0.453592 | 8797.87 | 15 | 131968.1 |
| Entrance Doors | 5 | EA | 80 | 0.453592 | 181.4368 | 15 | 2721.552 |
| HC Door Operators | 2 | EA | 30 | 0.453592 | 27.21552 | 20.1 | 547.032 |
| Interior Storefront | 416 | SF | 52 | 0.453592 | 9812.102 | 15 | 147181.5 |
| Light Monitors | 64 | SF | 4 | 0.453592 | 116.1196 | 1.38 | 160.245 |
| Mirrors | 96 | SF | 19 | 0.453592 | 827.3518 | 15 | 12410.28 |
| Glaze Sidelites & Borrow Lites | 1166.4 | SF | 4 | 0.453592 | 2116.279 | 15 | 31744.18 |
| Fire Lite Glazing | 365 | SF | 4 | 0.453592 | 662.2443 | 15 | 9933.665 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | Total | 2442141 |
| | | | | | | | |
| | | | | | | Total | 2637028 |
| | | | | | | | |
| | | | | | | | |
| Plaster and Drywall Systems | | | | | | | |
| Structural Stud Wall Framing | 14790 | SF | 2 | 0.453592 | 13417.25 | 22.6 | 303229.9 |
| Exterior Wall Furring | 4650.212 | SF | 1.5 | 0.453592 | 3163.948 | 22.6 | 71505.23 |
| Struct Stud Walls at Penthouse | 4345 | SF | 2 | 0.453592 | 3941.714 | 22.6 | 89082.75 |
| Perimeter Drywall | 14780 | SF | 3.4 | 0.453592 | 22793.91 | 1.8 | 41029.03 |
| Non-Organic Wall Board Premium | 2847 | SF | 3.4 | 0.453592 | 4390.68 | 1.8 | 7903.224 |
| Quad-Layer Drywall Prem @ Reverb Rm. | 596 | SF | 3.9 | 0.453592 | 1054.329 | 1.8 | 1897.793 |
| Shaft Wall, Incl Fire Caulk | 340 | LF | 20 | 0.453592 | 3084.426 | 22.6 | 69708.02 |
| One Hour Walls, Incl Fire Caulk | 499 | LF | 20 | 0.453592 | 4526.848 | 22.6 | 102306.8 |
| Abuse Resistant Drywall Premium | 12668.73 | SF | 6 | 0.453592 | 34478.59 | 1.8 | 62061.47 |
| Drywall @ Columns | 1000 | SF | 3.4 | 0.453592 | 1542.213 | 1.8 | 2775.983 |
| Suspended Drywall Ceilings | 5378 | SF | 0.125 | 0.453592 | 304.9272 | 1.8 | 548.869 |
| Drywall Bulkheads | 65 | LF | 13.6 | 0.453592 | 400.9753 | 1.8 | 721.7556 |
| Aluminum Reveal Premium | 1022 | LF | 21.375 | 0.453592 | 9908.831 | 154 | 1525960 |
| Fireproofing @ Penthouse | 7615 | SF | 2.5 | 0.453592 | 8635.258 | 22.6 | 195156.8 |
| Metal Panel Cover - Painted | 20 | SF | 21.375 | 0.453592 | 193.9106 | 154 | 29862.23 |
| Safing Insulation | 1306.098 | LF | 4 | 0.453592 | 2369.743 | 16.8 | 39811.68 |
| | | | | | | | |
| | | | | | | Total | 2543561 |
| | | | | | | | |
| Ceramic Tile | | | | | | | |
| Ceramic Tile | 807 | SF | 4.7 | 0.453592 | 1720.429 | 12 | 20645.15 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ceramic Tile Walls | 2438 | SF | 4.7 | 0.453592 | 5197.529 | 12 | 62370.35 |
| Tile Base | 305 | SF | 4.7 | 0.453592 | 650.2241 | 12 | 7802.69 |
| | | | | | | Total | 90818.19 |
| | | | | | | | |
| Acoustical Treatment | | | | | | | |
| 2x2 Acoustic Ceilings | 4672 | SF | 1 | 0.453592 | 2119.182 | 1.8 | 3814.527 |
| 2x2 Acoustic Ceilings (Washable) | 3478 | SF | 1 | 0.453592 | 1577.593 | 1.8 | 2839.667 |
| Acoustic Cloud Ceilings | 550 | SF | 1 | 0.453592 | 249.4756 | 1.8 | 449.0561 |
| Metal Ceiling System | 622 | SF | 122.675 | 0.453592 | 34610.82 | 25.1 | 868731.5 |
| Perforated MWP & Insulation | 234.3 | SF | 2 | 0.453592 | 212.5532 | 20.1 | 4272.32 |
| | | | | | | | |
| | | | | | | Total | 880107.1 |
| | | | | | | | |
| Painting and Wall Coverings | | | | | | | |
| Stair & Service Room Walls | 4919.854 | SF | 0.092903 | 1 | N/A | 21 | 9598.454 |
| Paint Stairs and Handrails | 115.1429 | LF | 0.092903 | 0.666667 | N/A | 21 | 149.7596 |
| Finish Doors & Frames | 92 | EA | 0.092903 | 0.0929 | N/A | 21 | 16.67449 |
| CMU Partitions (Incl Blk Filler) | 30028 | SF | 0.092903 | 1 | N/A | 21 | 58583.52 |
| Paint Drywall Walls | 47819.83 | SF | 0.092903 | 1 | N/A | 21 | 93294.72 |
| Epoxy Paint Walls | 16613.73 | SF | 1 | 1 | N/A | 70 | 1162961 |
| Whiteboard Paint | 365 | SF | 1 | 1 | N/A | 97 | 35405 |
| Polymix Wall Coatings | 5980.941 | SF | 0.092903 | 1 | N/A | 21 | 11668.59 |
| Drywall Ceilings | 5443 | SF | 0.092903 | 1 | N/A | 21 | 10619.09 |
| | | | | | | | |
| | | | | | | Total | 1382297 |
| | | | | | | | |
| | | | | | | Total | 4896783 |
| | | | | | | | |
| Flooring | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Clear Floor Sealer, One Coat | 24067.44 | SF | 344.9666 | 0.453592 | 156.4741 | 97 | 15177.99 |
| Resilient Base | 4426.274 | LF | 0.325 | 0.453592 | 652.5098 | 68.6 | 44762.18 |
| Metal Base | 102 | LF | 0.204458 | 0.453593 | 9.459569 | 56.7 | 536.3575 |
| Resinous Flooring | 7596 | SF | 3 | 0.453592 | 10336.45 | 2 | 20672.91 |
| Carpet Tiles | 383 | SY | 0.836127 | 1 | 320.2368 | 178 | 57002.15 |
| | | | | | | | |
| | | | | | | Total | 138151.6 |
| | | | | | | | |
| | | | | | | | |
| Specialties | | | | | | | |
| Marker & Bulletin Boards | 231 | SF | 1.47 | 0.453592 | 154.0262 | 15 | 2310.394 |
| Toilet Partitions | 10 | EA | 234 | 0.453592 | 1061.405 | 76.7 | 81409.78 |
| Dust Strip Curtain @ Rm 1544 | 25 | LF | 0.75 | 0.453592 | 8.50485 | 91 | 773.9414 |
| Unistrut Tank Supports | 102 | LF | 3.489 | 0.453592 | 161.4234 | 20.1 | 3244.611 |
| Unistrut TV Supports | 9 | EA | 10 | 0.453592 | 40.82328 | 20.1 | 820.5479 |
| Corner Guards | 43.78421 | EA | 7 | 0.453592 | 139.0212 | 91 | 12650.93 |
| Access Flooring | 309 | SF | 7 | 0.453592 | 981.1195 | 20.1 | 19720.5 |
| Access Flooring A. Chamber | 119 | SF | 7 | 0.453592 | 377.8421 | 20.1 | 7594.627 |
| Fire Extinguishers and Cabinets | 8.3052 | EA | 7.5 | 1 | 62.289 | 20.1 | 1252.009 |
| | | | | | | | |
| | | | | | | Total | 129777.3 |
| | | | | | | | |
| Equipment and Furnishings | | | | | | | |
| Projection Screens | 2 | EA | 34 | 0.453592 | 30.84426 | 77.2 | 2381.177 |
| Movable Wall (Glass & Wood) | 143 | LF | 56 | 0.453592 | 3632.365 | 10.4 | 37776.59 |
| Sliding Barn Doors | 9 | EA | 122 | 0.453592 | 498.044 | 20.1 | 10010.68 |
| Dyno Bedplate, 4'x15' | 1 | EA | 500 | 0.453592 | 226.796 | 20.1 | 4558.6 |
| Lab Cswrk, Mtl, resin top, Base & Wall | 560 | LF | 35 | 0.453592 | 8890.403 | 53.29 | 473769.6 |
| Lab Cswrk, Mobile, Mtl, resin top, Base & Wall | 633 | LF | 35 | 0.453592 | 10049.33 | 53.29 | 535528.8 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Lab Cswrk, Shelving | 239 | LF | 0.1132 | 0.593592 | 16.05951 | 20.1 | 322.7962 |
| Lab Cswrk, Tall Storage Cabinets | 62 | LF | 90 | 0.453592 | 2531.043 | 14.72 | 37256.96 |
| Fume Hoods Low flow, hi-eff.,72 in. | 13 | EA | 500 | 0.453592 | 2948.348 | 20.1 | 59261.79 |
| Bio Safety Cabinet | 4 | EA | 891 | 0.453592 | 1616.602 | 20.1 | 32493.7 |
| Entrance Mats | 152 | SF | 0.1319 | 0.45352 | 9.092532 | 68.6 | 623.7477 |
| Black out Shades | 122 | SF | 3 | 0.45352 | 165.9883 | 68.6 | 11386.8 |
| Meccho Shades | 963 | SF | 3 | 0.45352 | 1310.219 | 68.6 | 89881.04 |
| | | | | | | | |
| | | | | | | Total | 1295252 |
| | | | | | | | |
| | | | | | | Total | 1425030 |
| | | | | | | | |
| Plumbing | | | | | | | |
| EWC | 4 | EA | 3 | 0.453592 | 5.443104 | 56.7 | 308.624 |
| Emergency Eyewashes | 1 | EA | 3 | 0.453592 | 1.360776 | 56.7 | 77.156 |
| Drains/Carriers | 40 | EA | 1.5 | 0.453592 | 27.21552 | 56.7 | 1543.12 |
| Instantaneous Water Heaters - Steam to Water | 2 | EA | 4.95 | 0.453592 | 4.490561 | 32.78 | 147.1813 |
| Circ Pump DHW Return | 1 | EA | 7.15 | 0.453592 | 3.243183 | 26.2 | 84.97139 |
| Clear Water Duplex Sump Pumps | 1 | EA | 38.25 | 0.453592 | 17.34989 | 26.2 | 454.5672 |
| Duplex Sewage Ejector Pumps | 1 | EA | 545 | 0.453592 | 247.2076 | 20.1 | 4968.874 |
| Air Compressors | 3 | EA | 116 | 0.453592 | 157.85 | 26.2 | 4135.67 |
| Air Receiver | 1 | EA | 870 | 0.453592 | 394.625 | 20.1 | 7931.963 |
| Roof Drains (see A-105) | 14 | EA | 17 | 0.453592 | 107.9549 | 26.2 | 2828.418 |
| Water Softener Skid | 2 | EA | 211 | 0.453592 | 191.4158 | 25 | 4785.396 |
| Waste Effluent Sample Port | 1 | LS | 1 | 0.453592 | 0.453592 | 67.5 | 30.61746 |
| Natural Gas Meter Station | 1 | EA | 2.7 | 1 | 2.7 | 20.1 | 54.27 |
| PVF - RO 316L SS Humidif. Piping | 200 | LF | 2.228 | 0.453592 | 202.1206 | 67.5 | 13643.14 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| PVF - RO PPE Circ. Loop w/ U-bend end Use Points | 600 | LF | 2.228 | 0.453592 | 606.3618 | 67.5 | 40929.42 |
| Domestic Water Pre-Heat Exchanger | 1 | EA | 560 | 0.453592 | 254.0115 | 20.1 | 5105.632 |
| Domestic Water Backflow Preventer | 4 | EA | 5 | 0.453592 | 9.07184 | 44 | 399.161 |
| BioDiesel Storage Tank 40 Gal | 1 | EA | 26 | 0.453592 | 11.79339 | 76.7 | 904.5532 |
| | | | | | | | |
| | | | | | | Total | 88332.73 |
| | | | | | | | |
| | | | | | | | |
| HVAC Systems | | | | | | | |
| Chiller - Modular (Climacool UCW) | 157 | TON | 7108.07 | 0.453592 | 3224.164 | 22.6 | 72866.1 |
| Chiller - Air Cooled (York YMC) | 289 | TON | 16200 | 0.453592 | 7348.19 | 22.6 | 166069.1 |
| Chiller Air Cooled Condensing Unit | 8 | TON | 1348 | 0.453592 | 611.442 | 34.7 | 21217.04 |
| Chilled Water - Pumps | 80 | HP | INC. ABOVE | | | | |
| Chilled Water - VFD | 80 | HP | INC. ABOVE | | | | |
| Chilled Glycol - Pumps | 40 | HP | INC. ABOVE | | | | |
| Chilled Glycol - VFD | 40 | HP | INC. ABOVE | | | | |
| Chilled Beam (Tertiary) - Pumps | 15 | HP | 300 | 0.453592 | 136.0776 | 26.2 | 3565.233 |
| Chilled Beam (Tertiary) - VFD | 15 | HP | 300 | 0.453592 | 136.0776 | 26.2 | 3565.233 |
| Misc In-Line Pumps (9,10,11,12, & 15) | 7 | HP | 181 | 0.453592 | 82.10015 | 26.2 | 2151.024 |
| Server - Pump (13, 14 & 15) | 12 | HP | 181 | 0.453592 | 82.10015 | 26.2 | 2151.024 |
| Server - VFD | 10 | HP | 181 | 0.453592 | 82.10015 | 26.2 | 2151.024 |
| AHU-1, -2 Labs | 40000 | CFM | 23760 | 0.453592 | 10777.35 | 22.6 | 243568 |
| AHU-1, -2 - VFD | 80 | HP | INC. ABOVE | | | | |
| AHU-3 Composites Lab | 2160 | CFM | 1694 | 0.453592 | 768.3848 | 22.6 | 17365.5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| AHU-4 Dyno Comb. | 1200 | CFM | 1330 | 0.453592 | 603.2774 | 22.6 | 13634.07 |
| AHU-4 - VFD | 15 | HP | INC. ABOVE | | | | |
| AHU-5 Dyno Vent | 10000 | CFM | 3968 | 0.453592 | 1799.853 | 22.6 | 40676.68 |
| HRU-1, -2 | 36000 | CFM | INC. ABOVE | | | | |
| Humidifiers (AHU & Atomizing) | 500 | LB | 220 | 0.453592 | 99.79024 | 22.6 | 2255.259 |
| Liebert Unit @ Server Room | 10 | TON | 2000 | 0.453592 | 907.184 | 22.6 | 20502.36 |
| FCU | 14 | EA | 170 | 0.453592 | 1079.549 | 32.78 | 35382.97 |
| CUH | 7 | EA | 175 | 0.453592 | 555.6502 | 22.6 | 12557.69 |
| Fin Tube Radiation Panels | 155 | LF | 3.5 | 0.453592 | 246.0737 | 32.78 | 8065.236 |
| VAV Terminal Units - Hydronic | 62 | EA | 85 | 0.453592 | 2390.43 | 32.78 | 78348.01 |
| Chilled Beams | 33 | EA | 22.3 | 2 | 1471.8 | 22.6 | 33262.68 |
| Phoenix Air Valves | 60 | EA | 9 | 0.453592 | 244.9397 | 22.6 | 5535.637 |
| Sound Attenuators (Duct Stream) | 28 | EA | 11 | 0.453592 | 139.7063 | 22.6 | 3157.363 |
| 6" Steam Meter | 1 | EA | 94.2 | 0.453592 | 42.72837 | 22.6 | 965.6611 |
| HE-1, -2 (Plate & Frame) | 3 | EA | INC IN AHU | | | | |
| HE-3, -4 (Shell & Tube (Test Cell)) | 2 | EA | INC IN AHU | | | | |
| HHW - Pumps | 40 | HP | 463 | 0.453592 | 210.0131 | 26.2 | 5502.343 |
| HHW - VFD | 40 | HP | 463 | 0.453592 | 210.0131 | 26.2 | 5502.343 |
| Steam Condensate Pump | 1 | EA | 153 | 0.453592 | 69.39958 | 26.2 | 1818.269 |
| Air Separators>10" | 5 | EA | 100 | 0.453592 | 226.796 | 22.6 | 5125.59 |
| Expansion Tanks | 4 | EA | 100 | 0.453592 | 181.4368 | 20.1 | 3646.88 |
| Air Intake Louver/Damper @ Penthouse | 1 | EA | 36 | 0.453592 | 16.32931 | 22.6 | 369.0425 |
| Intake Hood | 1 | EA | 200 | 0.453592 | 90.7184 | 22.6 | 2050.236 |
| Relief Hood | 2 | EA | 200 | 0.453592 | 181.4368 | 22.6 | 4100.472 |
| Water Filters | 3 | EA | 525 | 0.453592 | 714.4074 | 20.1 | 14359.59 |
| | | | | | | | |
| | | | | | | Total | 831487.7 |
| | | | | | | | |
| | | | | | | | |
| Electrical | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2000A Feeder | 75 | LF | | 0.453592 | | 35.4 | 1204.287 |
| 480/277V 2000A Swbd W/ Metering & (10) C/B | 1 | EA | 5000 | 0.453592 | 2267.96 | 22.6 | 51255.9 |
| 120/208V 225A 42Ckt. Pwr. Panel | 20 | EA | 140 | 0.453592 | 1270.058 | 31.05 | 39435.29 |
| 120/208V 400A 42Ckt. Pwr. Panel | 1 | EA | 208 | 0.453592 | 94.34714 | 31.05 | 2929.479 |
| 480/277V 100A 42Ckt. Ltg. Panel | 3 | EA | 135 | 0.453592 | 183.7048 | 31.05 | 5704.033 |
| 120/208V 800A 42Ckt. Pwr. Panel | 2 | EA | 225 | 0.453592 | 204.1164 | 31.05 | 6337.814 |
| 480/277V 225A 42Ckt. Ltg. Panel | 4 | EA | 140 | 0.453592 | 254.0115 | 31.05 | 7887.058 |
| 480/277V 400A 42Ckt. Dist. Panel | 1 | EA | 208 | 0.453592 | 94.34714 | 31.05 | 2929.479 |
| 480/277V 600A 42Ckt. Dist. Panel | 3 | EA | 208 | 0.453592 | 283.0414 | 31.05 | 8788.436 |
| 480/277V 800A 42Ckt. Ltg. Panel | 2 | EA | 225 | 0.453592 | 204.1164 | 31.05 | 6337.814 |
| 60A NEMA1 F Disc. Switch | 5 | EA | 57 | 0.453592 | 129.2737 | 31.05 | 4013.949 |
| 112.5KVA Dry Type Transformer | 1 | EA | 735 | 0.453592 | 333.3901 | 32.15 | 10716.83 |
| 225KVA Dry Type Transformer | 2 | EA | 1910 | 0.453592 | 1732.721 | 32.15 | 55698.33 |
| 330KVA Dry Type Transformer | 1 | EA | 2050 | 0.453592 | 929.8636 | 32.15 | 29890.47 |
| SATEC PM174 Feeder Breaker Meters (AEI Comment) | 5 | EA | 2.7 | 0.453592 | 6.123492 | 22.6 | 138.3909 |
| 100A EMT Feeder | 1,200 | LF | 0.428 | 0.453592 | 232.9649 | 35.4 | 16119.86 |
| | | | | 0.64 | 0.453592 | 22.6 | 7872.906 |
| 150A EMT Feeder | 2,470 | LF | 0.8385 | 0.453592 | 939.4321 | 35.4 | 57310.29 |
| | | | | 0.95 | 0.453592 | 22.6 | 24054.39 |
| 200A EMT Feeder | 200 | LF | 1.2885 | 0.453592 | 116.8907 | 35.4 | 6393.189 |
| | | | | 1.1 | 0.453592 | 22.6 | 2255.259 |
| 225A EMT Feeder | 1,170 | LF | 1.65 | 0.453592 | 875.6594 | 35.4 | 47789.77 |
| | | | | 1.4 | 0.453592 | 22.6 | 16791.43 |
| 300A EMT Feeder | 120 | LF | 3.369 | 0.453592 | 183.3782 | 35.4 | 8213.785 |
| | | | | 1.4 | 0.453592 | 22.6 | 1722.198 |
| 400A EMT Feeder | 210 | LF | 3.561 | 0.453592 | 339.2006 | 35.4 | 16420.84 |
| | | | | 2.05 | 0.453592 | 22.6 | 4413.133 |
| 450A EMT Feeder | 160 | LF | 5.166 | 0.453592 | 374.921 | 35.4 | 16634.59 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | 2.05 | 0.453592 | 22.6 | 3362.387 |
| 600A EMT Feeder | 450 | LF | 7.645 | 0.453592 | 1560.47 | 35.4 | 66773.21 |
| | | | | 2.5 | 0.453592 | 22.6 | 11532.58 |
| 800A EMT Feeder | 230 | LF | 10.09 | 0.453592 | 1052.651 | 35.4 | 45987.6 |
| | | | | 3.7 | 0.453592 | 22.6 | 8723.753 |
| 100A NEMA1 F Disc. Switch for Oven and Autoclave | 2 | EA | 57 | 0.453592 | 51.70949 | 22.6 | 1168.634 |
| Chiller Hook-up 500A EMT Feeder | 120 | LF | 7.645 | 0.453592 | 416.1253 | 35.4 | 17252.63 |
| | | | | 2.05 | 0.453592 | 22.6 | 2521.79 |
| Pumps Hook-up 100A EMT Feeder | 700 | LF | 7.645 | 0.453592 | 2427.398 | 35.4 | 90522.4 |
| | | | | 0.64 | 0.453592 | 22.6 | 4592.528 |
| 20A EMT Feeder | 3,470 | LF | 0.0792 | 0.453592 | 124.658 | 35.4 | 1018203 |
| | | | | 28.5 | 0.453592 | 22.6 | 1013790 |
| Light Switches | 187 | EA | 0.2 | 0.453592 | 16.96434 | 62.55 | 1061.12 |
| Motion Detectors | 94 | EA | 0.25 | 0.453592 | 10.65941 | 62.55 | 666.7462 |
| Photocell (Daylighting Control) | 23 | EA | 0.25 | 0.453592 | 2.608154 | 62.55 | 163.14 |
| IR Sensor (Daylighting Control) | 23 | EA | 0.25 | 0.453592 | 2.608154 | 62.55 | 163.14 |
| Power Pack (Daylighting Control) | 23 | EA | 3 | 0.453592 | 31.29785 | 62.55 | 1957.68 |
| Wall Outlets | 426 | EA | 0.2 | 0.453592 | 38.64604 | 62.55 | 2417.31 |
| Wiremold 4000 Series | 1,000 | LF | 0.4 | 0.453592 | 181.4368 | 83.1 | 15077.4 |
| 400kW Generator (W/ Enclosure) | 1 | EA | 7284 | 0.453592 | 3303.964 | 32.15 | 106205.9 |
| 300A Transfer Switch | 1 | EA | 395 | 0.453592 | 179.1688 | 32.15 | 5759.382 |
| 600A Transfer Switch | 1 | EA | 395 | 0.453592 | 179.1688 | 32.15 | 5759.382 |
| 800A Feeder | 100 | LF | 6.4759 | 0.453592 | | 35.4 | 10641.81 |
| | | | | 3.7 | 0.453592 | 1.45 | 243.3521 |
| 3/4 Inch EMT Empty Conduit | 5,355 | LF | 0.64 | 0.453592 | | 35.4 | 55031.09 |
| Cable Tray | 1,060 | LF | 0.4 | 0.453592 | 192.323 | 83.1 | 15982.04 |
| 4 Inch EMT Empty Conduit | 450 | LF | 3.7 | 0.453592 | | 35.4 | 26735.17 |
| Cable TV Outlets (Conduit Stub & Wiring) | 35 | EA | 0.2 | 0.453592 | 3.175144 | 22.6 | 71.75825 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | Total | 1889751 |
| | | | | | | | |
| | | | | | | | |
| Excavation | Total | | 4713384 | MJ | 1309273 | kWh | 12.71% |
| Structural | Total | | 6923702 | MJ | 1923250 | kWh | 18.68% |
| Masonry | Total | | 778305.8 | MJ | 216196.1 | kWh | 2.10% |
| Carpentry | Total | | 207,768 | MJ | 57713.24 | kWh | 0.56% |
| Roofing and Flashing | Total | | 12543517 | MJ | 3484310 | kWh | 33.83% |
| Doors and Glazing | Total | | 2637028 | MJ | 732507.8 | kWh | 7.11% |
| Plaster and Ceilings | Total | | 4896783 | MJ | 1360218 | kWh | 13.21% |
| Flooring | Total | | 138151.6 | MJ | 38375.44 | kWh | 0.37% |
| Equipment | Total | | 1425030 | MJ | 395841.6 | kWh | 3.84% |
| Fire Protection and Plumbing | Total | | 88332.73 | MJ | 24536.87 | kWh | 0.24% |
| HVAC | Total | | 831487.7 | MJ | 230968.8 | kWh | 2.24% |
| Electrical | Total | | 1889751 | MJ | 524930.7 | kWh | 5.10% |
| | | | | | | | |
| | Total | | 37073239 | MJ | 10298122 | kWh | 100.00% |

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**Photovoltaic Baseline Net-Zero and Carbon Table**

| | | | | | |
|---|---|---|---|---|---|
| PV Embodied Energy | | 4750 | MJ/m^2 | | |
| | | | | | |
| | | 25.0022238 | MJ | | |
| | | | | | |
| | | 6.945062166 | kWh | | |
| | | | | | |
| PV array Size | | 17.65 | Ft^2 | | |
| | | | | | |
| | | 189.9831007 | m^2 | | |
| | | | | | |
| Total Embodied Energy | | | | | |
| | | | | | |
| | | 10297787 | kWh | | |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Per Array: | | | | | |
| | | 2574447 | kWh | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Ann. Operational Energy | | | | | |
| | | | | | |
| Electrical: | | 2167918 | kWh | | |
| | | | | | |
| Steam: | | 2982362 | kWh | | |
| | | | | | |
| | | | | | |
| Year | Embodied | Operational | Solar | Solar Decay | |
| 1 | 102977.9 | 5,150,280 | 98060.72 | 97.00% | 367.63 |
| 2 | 102977.9 | 5,150,280 | 98060.72 | 96.30% | 364.98 |
| 3 | 102977.9 | 5,150,280 | 98060.72 | 95.60% | 362.32 |
| 4 | 102977.9 | 5,150,280 | 98060.72 | 94.90% | 359.67 |
| 5 | 102977.9 | 5,150,280 | 98060.72 | 94.20% | 357.02 |
| 6 | 102977.9 | 5,150,280 | 98060.72 | 93.50% | 354.37 |
| 7 | 102977.9 | 5,150,280 | 98060.72 | 92.80% | 351.71 |
| 8 | 102977.9 | 5,150,280 | 98060.72 | 92.10% | 349.06 |
| 9 | 102977.9 | 5,150,280 | 98060.72 | 91.40% | 346.41 |
| 10 | 102977.9 | 5,150,280 | 98060.72 | 90.70% | 343.75 |
| 11 | 102977.9 | 5,150,280 | 98060.72 | 90.00% | 341.10 |
| 12 | 102977.9 | 5,150,280 | 98060.72 | 89.30% | 338.45 |
| 13 | 102977.9 | 5,150,280 | 98060.72 | 88.60% | 335.79 |
| 14 | 102977.9 | 5,150,280 | 98060.72 | 87.90% | 333.14 |
| 15 | 102977.9 | 5,150,280 | 98060.72 | 87.20% | 330.49 |
| 16 | 102977.9 | 5,150,280 | 98060.72 | 86.50% | 327.84 |
| 17 | 102977.9 | 5,150,280 | 98060.72 | 85.80% | 325.18 |
| 18 | 102977.9 | 5,150,280 | 98060.72 | 85.10% | 322.53 |
| 19 | 102977.9 | 5,150,280 | 98060.72 | 84.40% | 319.88 |
| 20 | 102977.9 | 5,150,280 | 98060.72 | 83.70% | 317.22 |
| 21 | 102977.9 | 5,150,280 | 98060.72 | 83.00% | 314.57 |
| 22 | 102977.9 | 5,150,280 | 98060.72 | 82.30% | 311.92 |
| 23 | 102977.9 | 5,150,280 | 98060.72 | 81.60% | 309.26 |
| 24 | 102977.9 | 5,150,280 | 98060.72 | 80.90% | 306.61 |
| 25 | 102977.9 | 5,150,280 | 98060.72 | 80.20% | 303.96 |
| | | | | | |
| Total | 2574447 | 128,757,000 | 2,451,518 | | 8,027.22 |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | | 133782965 | 133782965 | | 133,782,965 |
| | | No PV Deg. | PV Deg. | | |
| | Carb. N. | 14,708 | 16,668 | | 16666.164 |
| | | | | | 16,666 |
| | | $6,206,776.00 | $7,033,896.00 | | -$11,172.01 |
| | | | | | |
| | | 128757000 | | | |
| | | No PV Deg. | PV Deg. | | |
| | Net-Zero | 13,698 | 16,040 | | |
| | | | | | |
| | | $5,780,367.45 | $6,768,900.57 | | |

**Photovoltaic Building Lifespan Net-Zero and Carbon Table No Embodied Repair**

| | | | | | | |
|---|---|---|---|---|---|---|
| PV AC per year | | 379 | | | | |
| | | | | | | |
| PV Embodied Energy | | 4750 | MJ/m^2 | | | |
| | | | | | | |
| | | 25.0022238 | MJ | | | |
| | | | | | | |
| | | 6.945062166 | kWh | | | |
| | | | | | | |
| PV array Size | | 17.65 | Ft^2 | | | |
| | | | | | | |
| | | 189.9831007 | m^2 | | | |
| | | | | | | |
| Initial Embodied Energy | | | | | | |
| | | | | | | |
| | | 10297787 | kWh | | | |
| | | | | | | |
| Initial Ann. Operational Energy | | | | | | |
| | | | | | | |
| Electrical: | | 2167918 | kWh | | | |
| | | | | | | |
| Steam: | | 2982362 | kWh | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| Year | Embodied | Base Op. Energy | HVAC EDEC | Boiler EDEC | Solar Decay | |
| 1 | 10,297,787 | 3,453,161 | 663,563 | 1,033,556 | 97.00% | 367.63 |
| 2 | 0 | 3,453,161 | 669,111 | 1,038,750 | 96.30% | 364.98 |
| 3 | 0 | 3,453,161 | 674,706 | 1,043,970 | 95.60% | 362.32 |
| 4 | 0 | 3,453,161 | 680,347 | 1,049,216 | 94.90% | 359.67 |
| 5 | 0 | 3,453,161 | 686,036 | 1,054,488 | 94.20% | 357.02 |
| 6 | 0 | 3,453,161 | 691,772 | 1,059,787 | 93.50% | 354.37 |
| 7 | 0 | 3,453,161 | 697,556 | 1,065,113 | 92.80% | 351.71 |
| 8 | 0 | 3,453,161 | 703,389 | 1,070,465 | 92.10% | 349.06 |
| 9 | 0 | 3,453,161 | 709,270 | 1,075,844 | 91.40% | 346.41 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 10 | 0 | 3,453,161 | 715,201 | 1,081,250 | 90.70% | 343.75 |
| 11 | 0 | 3,453,161 | 721,181 | 1,086,684 | 90.00% | 341.10 |
| 12 | 0 | 3,453,161 | 727,211 | 1,092,145 | 89.30% | 338.45 |
| 13 | 0 | 3,453,161 | 733,291 | 1,097,633 | 88.60% | 335.79 |
| 14 | 0 | 3,453,161 | 739,422 | 1,103,148 | 87.90% | 333.14 |
| 15 | 0 | 3,453,161 | 745,605 | 1,108,692 | 87.20% | 330.49 |
| 16 | 0 | 3,453,161 | 751,839 | 1,114,263 | 86.50% | 327.84 |
| 17 | 0 | 3,453,161 | 758,125 | 1,119,863 | 85.80% | 325.18 |
| 18 | 0 | 3,453,161 | 764,464 | 1,125,490 | 85.10% | 322.53 |
| 19 | 0 | 3,453,161 | 770,856 | 1,131,146 | 84.40% | 319.88 |
| 20 | 0 | 3,453,161 | 777,302 | 1,136,830 | 83.70% | 317.22 |
| 21 | 0 | 3,453,161 | 783,801 | 1,142,543 | 83.00% | 314.57 |
| 22 | 0 | 3,453,161 | 790,355 | 1,148,284 | 82.30% | 311.92 |
| 23 | 0 | 3,453,161 | 796,963 | 1,154,054 | 81.60% | 309.26 |
| 24 | 0 | 3,453,161 | 803,627 | 1,159,854 | 80.90% | 306.61 |
| 25 | 0 | 3,453,161 | 810,346 | 1,165,682 | 80.20% | 303.96 |
| Total | 10,297,787 | 86,329,025 | 18,365,339 | 27,458,748 | | 8,395 |
| | | | | | | |
| 26 | 15,189 | 3,453,161 | 817,122 | 1,171,540 | 97.00% | 367.63 |
| 27 | 0 | 3,453,161 | 823,954 | 1,177,427 | 96.30% | 364.98 |
| 28 | 0 | 3,453,161 | 830,843 | 1,183,344 | 95.60% | 362.32 |
| 29 | 0 | 3,453,161 | 837,790 | 1,189,290 | 94.90% | 359.67 |
| 30 | 0 | 3,453,161 | 844,795 | 1,195,266 | 94.20% | 357.02 |
| 31 | 221,140 | 3,453,161 | 663,563 | 1,033,556 | 93.50% | 354.37 |
| 32 | 0 | 3,453,161 | 669,111 | 1,038,750 | 92.80% | 351.71 |
| 33 | 0 | 3,453,161 | 674,706 | 1,043,970 | 92.10% | 349.06 |
| 34 | 0 | 3,453,161 | 680,347 | 1,049,216 | 91.40% | 346.41 |
| 35 | 0 | 3,453,161 | 686,036 | 1,054,488 | 90.70% | 343.75 |
| 36 | 0 | 3,453,161 | 691,772 | 1,059,787 | 90.00% | 341.10 |
| 37 | 0 | 3,453,161 | 697,556 | 1,065,113 | 89.30% | 338.45 |
| 38 | 0 | 3,453,161 | 703,389 | 1,070,465 | 88.60% | 335.79 |
| 39 | 0 | 3,453,161 | 709,270 | 1,075,844 | 87.90% | 333.14 |
| 40 | 0 | 3,453,161 | 715,201 | 1,081,250 | 87.20% | 330.49 |
| 41 | 0 | 3,453,161 | 721,181 | 1,086,684 | 86.50% | 327.84 |
| 42 | 0 | 3,453,161 | 727,211 | 1,092,145 | 85.80% | 325.18 |
| 43 | 0 | 3,453,161 | 733,291 | 1,097,633 | 85.10% | 322.53 |
| 44 | 0 | 3,453,161 | 739,422 | 1,103,148 | 84.40% | 319.88 |
| 45 | 0 | 3,453,161 | 745,605 | 1,108,692 | 83.70% | 317.22 |
| 46 | 0 | 3,453,161 | 751,839 | 1,114,263 | 83.00% | 314.57 |
| 47 | 0 | 3,453,161 | 758,125 | 1,119,863 | 82.30% | 311.92 |
| 48 | 0 | 3,453,161 | 764,464 | 1,125,490 | 81.60% | 309.26 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 49 | 0 | 3,453,161 | 770,856 | 1,131,146 | 80.90% | 306.61 |
| 50 | 0 | 3,453,161 | 777,302 | 1,136,830 | 80.20% | 303.96 |
| Total | 236,329 | 86,329,025 | 18,534,752 | 27,605,197 | | 8,395 |
| | | | | | | |
| 51 | 15,189 | 3,453,161 | 783,801 | 1,142,543 | 97.00% | 367.63 |
| 52 | 0 | 3,453,161 | 790,355 | 1,148,284 | 96.30% | 364.98 |
| 53 | 0 | 3,453,161 | 796,963 | 1,154,054 | 95.60% | 362.32 |
| 54 | 0 | 3,453,161 | 803,627 | 1,159,854 | 94.90% | 359.67 |
| 55 | 0 | 3,453,161 | 810,346 | 1,165,682 | 94.20% | 357.02 |
| 56 | 0 | 3,453,161 | 817,122 | 1,171,540 | 93.50% | 354.37 |
| 57 | 0 | 3,453,161 | 823,954 | 1,177,427 | 92.80% | 351.71 |
| 58 | 0 | 3,453,161 | 830,843 | 1,183,344 | 92.10% | 349.06 |
| 59 | 0 | 3,453,161 | 837,790 | 1,189,290 | 91.40% | 346.41 |
| 60 | 0 | 3,453,161 | 844,795 | 1,195,266 | 90.70% | 343.75 |
| 61 | 221,140 | 3,453,161 | 663,563 | 1,033,556 | 90.00% | 341.10 |
| 62 | 0 | 3,453,161 | 669,111 | 1,038,750 | 89.30% | 338.45 |
| 63 | 0 | 3,453,161 | 674,706 | 1,043,970 | 88.60% | 335.79 |
| 64 | 0 | 3,453,161 | 680,347 | 1,049,216 | 87.90% | 333.14 |
| 65 | 0 | 3,453,161 | 686,036 | 1,054,488 | 87.20% | 330.49 |
| 66 | 0 | 3,453,161 | 691,772 | 1,059,787 | 86.50% | 327.84 |
| 67 | 0 | 3,453,161 | 697,556 | 1,065,113 | 85.80% | 325.18 |
| 68 | 0 | 3,453,161 | 703,389 | 1,070,465 | 85.10% | 322.53 |
| 69 | 0 | 3,453,161 | 709,270 | 1,075,844 | 84.40% | 319.88 |
| 70 | 0 | 3,453,161 | 715,201 | 1,081,250 | 83.70% | 317.22 |
| 71 | 0 | 3,453,161 | 721,181 | 1,086,684 | 83.00% | 314.57 |
| 72 | 0 | 3,453,161 | 727,211 | 1,092,145 | 82.30% | 311.92 |
| 73 | 0 | 3,453,161 | 733,291 | 1,097,633 | 81.60% | 309.26 |
| 74 | 0 | 3,453,161 | 739,422 | 1,103,148 | 80.90% | 306.61 |
| 75 | 0 | 3,453,161 | 745,605 | 1,108,692 | 80.20% | 303.96 |
| Total | 236,329 | 86,329,025 | 18,697,257 | 27,748,022 | | 8,395 |
| | | | | | | |
| 76 | 15,189 | 3,453,161 | 751,839 | 1,114,263 | 97.00% | 367.63 |
| 77 | 0 | 3,453,161 | 758,125 | 1,119,863 | 96.30% | 364.98 |
| 78 | 0 | 3,453,161 | 764,464 | 1,125,490 | 95.60% | 362.32 |
| 79 | 0 | 3,453,161 | 770,856 | 1,131,146 | 94.90% | 359.67 |
| 80 | 0 | 3,453,161 | 777,302 | 1,136,830 | 94.20% | 357.02 |
| 81 | 0 | 3,453,161 | 783,801 | 1,142,543 | 93.50% | 354.37 |
| 82 | 0 | 3,453,161 | 790,355 | 1,148,284 | 92.80% | 351.71 |
| 83 | 0 | 3,453,161 | 796,963 | 1,154,054 | 92.10% | 349.06 |
| 84 | 0 | 3,453,161 | 803,627 | 1,159,854 | 91.40% | 346.41 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 85 | 0 | 3,453,161 | 810,346 | 1,165,682 | 90.70% | 343.75 |
| 86 | 0 | 3,453,161 | 817,122 | 1,171,540 | 90.00% | 341.10 |
| 87 | 0 | 3,453,161 | 823,954 | 1,177,427 | 89.30% | 338.45 |
| 88 | 0 | 3,453,161 | 830,843 | 1,183,344 | 88.60% | 335.79 |
| 89 | 0 | 3,453,161 | 837,790 | 1,189,290 | 87.90% | 333.14 |
| 90 | 0 | 3,453,161 | 844,795 | 1,195,266 | 87.20% | 330.49 |
| 91 | 0 | 3,453,161 | 851,859 | 1,201,273 | 86.50% | 327.84 |
| 92 | 0 | 3,453,161 | 858,982 | 1,207,309 | 85.80% | 325.18 |
| 93 | 0 | 3,453,161 | 866,164 | 1,213,376 | 85.10% | 322.53 |
| 94 | 0 | 3,453,161 | 873,406 | 1,219,473 | 84.40% | 319.88 |
| 95 | 0 | 3,453,161 | 880,709 | 1,225,601 | 83.70% | 317.22 |
| 96 | 0 | 3,453,161 | 888,073 | 1,231,760 | 83.00% | 314.57 |
| 97 | 0 | 3,453,161 | 895,498 | 1,237,950 | 82.30% | 311.92 |
| 98 | 0 | 3,453,161 | 902,986 | 1,244,171 | 81.60% | 309.26 |
| 99 | 0 | 3,453,161 | 910,536 | 1,250,423 | 80.90% | 306.61 |
| 100 | 0 | 3,453,161 | 918,149 | 1,256,707 | 80.20% | 303.96 |
| Total | 15,189 | 86,329,025 | 20,808,545 | 29,602,917 | | 8,395 |
| | | | | | | |
| TOTAL | 10,785,634 | 345,316,100 | 76,405,893 | 112,414,885 | | 33,579 |
| | | | | | | |
| | | | | 544,922,512 | | |
| | | | | | | |
| Carbon Neutral | | Total Modules needed | | 64,965 | | $28,714,649 |
| | | | | | | |
| | | Per Array | | 16,241 | | $7,178,662 |
| | | | | | | |
| | | | | | | |
| Net-Zero | | | | 534,136,878 | | |
| | | | | | | |
| | | Total Modules needed | | 63,627 | | $28,123,016 |
| | | | | | | |
| | | Per Array | | 15,907 | | $7,030,754 |

**Photovoltaic Building Lifespan Net-Zero and Carbon Table With Embodied Repair**

| | | | | | | |
|---|---|---|---|---|---|---|
| PV AC per year | | 379 | | | | |
| | | | | | | |
| PV Embodied Energy | | 4750 | MJ/m^2 | | | |
| | | | | | | |
| | | 25.0022238 | MJ | | | |
| | | | | | | |
| | | 6.94506217 | kWh | | | |
| | | | | | | |
| PV array Size | | 17.65 | Ft^2 | | | |
| | | | | | | |
| | | 189.983101 | m^2 | | | |
| | | | | | | |
| Initial Embodied Energy | | | | | | |
| | | | | | | |
| | | 10297787 | kWh | | | |
| | | | | | | |
| Initial Ann. Operational Energy | | | | | | |
| | | | | | | |
| Electrical: | | 2167918 | kWh | | | |
| | | | | | | |
| Steam: | | 2982362 | kWh | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| Year | Embodied | Base Op. Energy | HVAC EDEC | Boiler EDEC | Solar Decay | |
| 1 | 10,297,787 | 3,453,161 | 663,563 | 1,033,556 | 97.00% | 367.63 |
| 2 | 0 | 3,453,161 | 669,111 | 1,038,750 | 96.30% | 364.98 |
| 3 | 0 | 3,453,161 | 674,706 | 1,043,970 | 95.60% | 362.32 |
| 4 | 0 | 3,453,161 | 680,347 | 1,049,216 | 94.90% | 359.67 |
| 5 | 0 | 3,453,161 | 686,036 | 1,054,488 | 94.20% | 357.02 |
| 6 | 0 | 3,453,161 | 691,772 | 1,059,787 | 93.50% | 354.37 |
| 7 | 0 | 3,453,161 | 697,556 | 1,065,113 | 92.80% | 351.71 |
| 8 | 0 | 3,453,161 | 703,389 | 1,070,465 | 92.10% | 349.06 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 9 | 0 | 3,453,161 | 709,270 | 1,075,844 | 91.40% | 346.41 |
| 10 | 0 | 3,453,161 | 715,201 | 1,081,250 | 90.70% | 343.75 |
| 11 | 0 | 3,453,161 | 721,181 | 1,086,684 | 90.00% | 341.10 |
| 12 | 0 | 3,453,161 | 727,211 | 1,092,145 | 89.30% | 338.45 |
| 13 | 0 | 3,453,161 | 733,291 | 1,097,633 | 88.60% | 335.79 |
| 14 | 0 | 3,453,161 | 739,422 | 1,103,148 | 87.90% | 333.14 |
| 15 | 0 | 3,453,161 | 745,605 | 1,108,692 | 87.20% | 330.49 |
| 16 | 0 | 3,453,161 | 751,839 | 1,114,263 | 86.50% | 327.84 |
| 17 | 0 | 3,453,161 | 758,125 | 1,119,863 | 85.80% | 325.18 |
| 18 | 0 | 3,453,161 | 764,464 | 1,125,490 | 85.10% | 322.53 |
| 19 | 0 | 3,453,161 | 770,856 | 1,131,146 | 84.40% | 319.88 |
| 20 | 0 | 3,453,161 | 777,302 | 1,136,830 | 83.70% | 317.22 |
| 21 | 0 | 3,453,161 | 783,801 | 1,142,543 | 83.00% | 314.57 |
| 22 | 0 | 3,453,161 | 790,355 | 1,148,284 | 82.30% | 311.92 |
| 23 | 0 | 3,453,161 | 796,963 | 1,154,054 | 81.60% | 309.26 |
| 24 | 0 | 3,453,161 | 803,627 | 1,159,854 | 80.90% | 306.61 |
| 25 | 0 | 3,453,161 | 810,346 | 1,165,682 | 80.20% | 303.96 |
| Total | 10,297,787 | 86,329,025 | 18,365,339 | 27,458,748 | | 8,395 |
| | | | | | | |
| 26 | 15,227 | 3,453,161 | 817,122 | 1,171,540 | 97.00% | 367.63 |
| 27 | 0 | 3,453,161 | 823,954 | 1,177,427 | 96.30% | 364.98 |
| 28 | 0 | 3,453,161 | 830,843 | 1,183,344 | 95.60% | 362.32 |
| 29 | 0 | 3,453,161 | 837,790 | 1,189,290 | 94.90% | 359.67 |
| 30 | 0 | 3,453,161 | 844,795 | 1,195,266 | 94.20% | 357.02 |
| 31 | 274,214 | 3,453,161 | 663,563 | 1,033,556 | 93.50% | 354.37 |
| 32 | 0 | 3,453,161 | 669,111 | 1,038,750 | 92.80% | 351.71 |
| 33 | 0 | 3,453,161 | 674,706 | 1,043,970 | 92.10% | 349.06 |
| 34 | 0 | 3,453,161 | 680,347 | 1,049,216 | 91.40% | 346.41 |
| 35 | 0 | 3,453,161 | 686,036 | 1,054,488 | 90.70% | 343.75 |
| 36 | 0 | 3,453,161 | 691,772 | 1,059,787 | 90.00% | 341.10 |
| 37 | 0 | 3,453,161 | 697,556 | 1,065,113 | 89.30% | 338.45 |
| 38 | 0 | 3,453,161 | 703,389 | 1,070,465 | 88.60% | 335.79 |
| 39 | 0 | 3,453,161 | 709,270 | 1,075,844 | 87.90% | 333.14 |
| 40 | 0 | 3,453,161 | 715,201 | 1,081,250 | 87.20% | 330.49 |
| 41 | 0 | 3,453,161 | 721,181 | 1,086,684 | 86.50% | 327.84 |
| 42 | 0 | 3,453,161 | 727,211 | 1,092,145 | 85.80% | 325.18 |
| 43 | 0 | 3,453,161 | 733,291 | 1,097,633 | 85.10% | 322.53 |
| 44 | 0 | 3,453,161 | 739,422 | 1,103,148 | 84.40% | 319.88 |
| 45 | 0 | 3,453,161 | 745,605 | 1,108,692 | 83.70% | 317.22 |
| 46 | 0 | 3,453,161 | 751,839 | 1,114,263 | 83.00% | 314.57 |
| 47 | 0 | 3,453,161 | 758,125 | 1,119,863 | 82.30% | 311.92 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 48 | 0 | 3,453,161 | 764,464 | 1,125,490 | 81.60% | 309.26 |
| 49 | 0 | 3,453,161 | 770,856 | 1,131,146 | 80.90% | 306.61 |
| 50 | 0 | 3,453,161 | 777,302 | 1,136,830 | 80.20% | 303.96 |
| Total | 289,441 | 86,329,025 | 18,534,752 | 27,605,197 | | 8,395 |
| | | | | | | |
| 51 | 20,657 | 3,453,161 | 783,801 | 1,142,543 | 97.00% | 367.63 |
| 52 | 0 | 3,453,161 | 790,355 | 1,148,284 | 96.30% | 364.98 |
| 53 | 0 | 3,453,161 | 796,963 | 1,154,054 | 95.60% | 362.32 |
| 54 | 0 | 3,453,161 | 803,627 | 1,159,854 | 94.90% | 359.67 |
| 55 | 0 | 3,453,161 | 810,346 | 1,165,682 | 94.20% | 357.02 |
| 56 | 0 | 3,453,161 | 817,122 | 1,171,540 | 93.50% | 354.37 |
| 57 | 0 | 3,453,161 | 823,954 | 1,177,427 | 92.80% | 351.71 |
| 58 | 0 | 3,453,161 | 830,843 | 1,183,344 | 92.10% | 349.06 |
| 59 | 0 | 3,453,161 | 837,790 | 1,189,290 | 91.40% | 346.41 |
| 60 | 0 | 3,453,161 | 844,795 | 1,195,266 | 90.70% | 343.75 |
| 61 | 331,807 | 3,453,161 | 663,563 | 1,033,556 | 90.00% | 341.10 |
| 62 | 0 | 3,453,161 | 669,111 | 1,038,750 | 89.30% | 338.45 |
| 63 | 0 | 3,453,161 | 674,706 | 1,043,970 | 88.60% | 335.79 |
| 64 | 0 | 3,453,161 | 680,347 | 1,049,216 | 87.90% | 333.14 |
| 65 | 0 | 3,453,161 | 686,036 | 1,054,488 | 87.20% | 330.49 |
| 66 | 0 | 3,453,161 | 691,772 | 1,059,787 | 86.50% | 327.84 |
| 67 | 0 | 3,453,161 | 697,556 | 1,065,113 | 85.80% | 325.18 |
| 68 | 0 | 3,453,161 | 703,389 | 1,070,465 | 85.10% | 322.53 |
| 69 | 0 | 3,453,161 | 709,270 | 1,075,844 | 84.40% | 319.88 |
| 70 | 0 | 3,453,161 | 715,201 | 1,081,250 | 83.70% | 317.22 |
| 71 | 0 | 3,453,161 | 721,181 | 1,086,684 | 83.00% | 314.57 |
| 72 | 0 | 3,453,161 | 727,211 | 1,092,145 | 82.30% | 311.92 |
| 73 | 0 | 3,453,161 | 733,291 | 1,097,633 | 81.60% | 309.26 |
| 74 | 0 | 3,453,161 | 739,422 | 1,103,148 | 80.90% | 306.61 |
| 75 | 0 | 3,453,161 | 745,605 | 1,108,692 | 80.20% | 303.96 |
| Total | 352,464 | 86,329,025 | 18,697,257 | 27,748,022 | | 8,395 |
| | | | | | | |
| 76 | 22,632 | 3,453,161 | 751,839 | 1,114,263 | 97.00% | 367.63 |
| 77 | 0 | 3,453,161 | 758,125 | 1,119,863 | 96.30% | 364.98 |
| 78 | 0 | 3,453,161 | 764,464 | 1,125,490 | 95.60% | 362.32 |
| 79 | 0 | 3,453,161 | 770,856 | 1,131,146 | 94.90% | 359.67 |
| 80 | 0 | 3,453,161 | 777,302 | 1,136,830 | 94.20% | 357.02 |
| 81 | 0 | 3,453,161 | 783,801 | 1,142,543 | 93.50% | 354.37 |
| 82 | 0 | 3,453,161 | 790,355 | 1,148,284 | 92.80% | 351.71 |
| 83 | 0 | 3,453,161 | 796,963 | 1,154,054 | 92.10% | 349.06 |
| 84 | 0 | 3,453,161 | 803,627 | 1,159,854 | 91.40% | 346.41 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 85 | 0 | 3,453,161 | 810,346 | 1,165,682 | 90.70% | 343.75 |
| 86 | 0 | 3,453,161 | 817,122 | 1,171,540 | 90.00% | 341.10 |
| 87 | 0 | 3,453,161 | 823,954 | 1,177,427 | 89.30% | 338.45 |
| 88 | 0 | 3,453,161 | 830,843 | 1,183,344 | 88.60% | 335.79 |
| 89 | 0 | 3,453,161 | 837,790 | 1,189,290 | 87.90% | 333.14 |
| 90 | 0 | 3,453,161 | 844,795 | 1,195,266 | 87.20% | 330.49 |
| 91 | 0 | 3,453,161 | 851,859 | 1,201,273 | 86.50% | 327.84 |
| 92 | 0 | 3,453,161 | 858,982 | 1,207,309 | 85.80% | 325.18 |
| 93 | 0 | 3,453,161 | 866,164 | 1,213,376 | 85.10% | 322.53 |
| 94 | 0 | 3,453,161 | 873,406 | 1,219,473 | 84.40% | 319.88 |
| 95 | 0 | 3,453,161 | 880,709 | 1,225,601 | 83.70% | 317.22 |
| 96 | 0 | 3,453,161 | 888,073 | 1,231,760 | 83.00% | 314.57 |
| 97 | 0 | 3,453,161 | 895,498 | 1,237,950 | 82.30% | 311.92 |
| 98 | 0 | 3,453,161 | 902,986 | 1,244,171 | 81.60% | 309.26 |
| 99 | 0 | 3,453,161 | 910,536 | 1,250,423 | 80.90% | 306.61 |
| 100 | 0 | 3,453,161 | 918,149 | 1,256,707 | 80.20% | 303.96 |
| Total | 22,632 | 86,329,025 | 20,808,545 | 29,602,917 | | 8,395 |
| | | | | | | |
| TOTAL | 10,962,324 | 345,316,100 | 76,405,893 | 112,414,885 | | 33,579 |
| | | | | | | |
| | | | | 545,099,202 | | |
| | | | | | | |
| Carbon Neutral | | Total Modules needed | | 64,986 | | $28,723,960 |
| | | | | | | |
| | | Per Array | | 16,247 | | $7,180,990 |
| | | | | | | |
| | | | | | | |
| Net-Zero | | | | 534,136,878 | | |
| | | | | | | |
| | | Total Modules needed | | 63,627 | | $28,123,016 |
| | | | | | | |
| | | Per Array | | 15,907 | | $7,030,754 |

**Photovoltaic Building Lifespan Net-Zero and Carbon Table With Embodied Repair and Sliding Degradation**

| | | | | | | |
|---|---|---|---|---|---|---|
| PV AC per year | | 379 | | | | |
| | | | | | | |
| PV Embodied Energy | | 4750 | MJ/m^2 | | | |
| | | | | | | |
| | | 25.0022238 | MJ | | | |
| | | | | | | |
| | | 6.945062166 | kWh | | | |
| | | | | | | |
| PV array Size | | 17.65 | Ft^2 | | | |
| | | | | | | |
| | | 189.9831007 | m^2 | | | |
| | | | | | | |
| Initial Embodied Energy | | | | | | |
| | | | | | | |
| | | 10297787 | kWh | | | |
| | | | | | | |
| Initial Ann. Operational Energy | | | | | | |
| | | | | | | |
| Electrical: | | 2167918 | kWh | | | |
| | | | | | | |
| Steam: | | 2982362 | kWh | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| Year | Embodied | Base Op. Energy | HVAC EDEC | Boiler EDEC | Solar Decay | |
| 1 | 10,297,787 | 3,453,161 | 663,563 | 1,033,556 | 97.00% | 367.63 |
| 2 | 0 | 3,453,161 | 669,375 | 1,039,098 | 96.30% | 364.98 |
| 3 | 0 | 3,453,161 | 675,769 | 1,045,370 | 95.60% | 362.32 |
| 4 | 0 | 3,453,161 | 682,763 | 1,052,386 | 94.90% | 359.67 |
| 5 | 0 | 3,453,161 | 690,373 | 1,060,159 | 94.20% | 357.02 |
| 6 | 0 | 3,453,161 | 698,618 | 1,068,708 | 93.50% | 354.37 |
| 7 | 0 | 3,453,161 | 707,521 | 1,078,049 | 92.80% | 351.71 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 8 | 0 | 3,453,161 | 717,103 | 1,088,203 | 92.10% | 349.06 |
| 9 | 0 | 3,453,161 | 727,389 | 1,099,192 | 91.40% | 346.41 |
| 10 | 0 | 3,453,161 | 738,407 | 1,111,038 | 90.70% | 343.75 |
| 11 | 0 | 3,453,161 | 750,185 | 1,123,769 | 90.00% | 341.10 |
| 12 | 0 | 3,453,161 | 762,755 | 1,137,410 | 89.30% | 338.45 |
| 13 | 0 | 3,453,161 | 776,150 | 1,151,994 | 88.60% | 335.79 |
| 14 | 0 | 3,453,161 | 790,406 | 1,167,551 | 87.90% | 333.14 |
| 15 | 0 | 3,453,161 | 805,563 | 1,184,117 | 87.20% | 330.49 |
| 16 | 0 | 3,453,161 | 821,662 | 1,201,728 | 86.50% | 327.84 |
| 17 | 0 | 3,453,161 | 838,749 | 1,220,425 | 85.80% | 325.18 |
| 18 | 0 | 3,453,161 | 856,871 | 1,240,250 | 85.10% | 322.53 |
| 19 | 0 | 3,453,161 | 876,082 | 1,261,249 | 84.40% | 319.88 |
| 20 | 0 | 3,453,161 | 896,436 | 1,283,471 | 83.70% | 317.22 |
| 21 | 0 | 3,453,161 | 917,993 | 1,306,969 | 83.00% | 314.57 |
| 22 | 0 | 3,453,161 | 940,818 | 1,331,797 | 82.30% | 311.92 |
| 23 | 0 | 3,453,161 | 964,979 | 1,358,017 | 81.60% | 309.26 |
| 24 | 0 | 3,453,161 | 990,550 | 1,385,692 | 80.90% | 306.61 |
| 25 | 0 | 3,453,161 | 1,017,610 | 1,414,889 | 80.20% | 303.96 |
| Total | 10,297,787 | 86,329,025 | 19,977,687 | 29,445,084 | | 8,395 |
| | | | | | | |
| 26 | 15,227 | 3,453,161 | 1,046,244 | 1,445,681 | 97.00% | 367.63 |
| 27 | 0 | 3,453,161 | 1,076,544 | 1,478,147 | 96.30% | 364.98 |
| 28 | 0 | 3,453,161 | 1,108,607 | 1,512,367 | 95.60% | 362.32 |
| 29 | 0 | 3,453,161 | 1,142,538 | 1,548,432 | 94.90% | 359.67 |
| 30 | 0 | 3,453,161 | 1,178,451 | 1,586,434 | 94.20% | 357.02 |
| 31 | 274,214 | 3,453,161 | 663,563 | 1,033,556 | 93.50% | 354.37 |
| 32 | 0 | 3,453,161 | 669,375 | 1,039,098 | 92.80% | 351.71 |
| 33 | 0 | 3,453,161 | 675,769 | 1,045,370 | 92.10% | 349.06 |
| 34 | 0 | 3,453,161 | 682,763 | 1,052,386 | 91.40% | 346.41 |
| 35 | 0 | 3,453,161 | 690,373 | 1,060,159 | 90.70% | 343.75 |
| 36 | 0 | 3,453,161 | 698,618 | 1,068,708 | 90.00% | 341.10 |
| 37 | 0 | 3,453,161 | 707,521 | 1,078,049 | 89.30% | 338.45 |
| 38 | 0 | 3,453,161 | 717,103 | 1,088,203 | 88.60% | 335.79 |
| 39 | 0 | 3,453,161 | 727,389 | 1,099,192 | 87.90% | 333.14 |
| 40 | 0 | 3,453,161 | 738,407 | 1,111,038 | 87.20% | 330.49 |
| 41 | 0 | 3,453,161 | 750,185 | 1,123,769 | 86.50% | 327.84 |
| 42 | 0 | 3,453,161 | 762,755 | 1,137,410 | 85.80% | 325.18 |
| 43 | 0 | 3,453,161 | 776,150 | 1,151,994 | 85.10% | 322.53 |
| 44 | 0 | 3,453,161 | 790,406 | 1,167,551 | 84.40% | 319.88 |
| 45 | 0 | 3,453,161 | 805,563 | 1,184,117 | 83.70% | 317.22 |
| 46 | 0 | 3,453,161 | 821,662 | 1,201,728 | 83.00% | 314.57 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 47 | 0 | 3,453,161 | 838,749 | 1,220,425 | 82.30% | 311.92 |
| 48 | 0 | 3,453,161 | 856,871 | 1,240,250 | 81.60% | 309.26 |
| 49 | 0 | 3,453,161 | 876,082 | 1,261,249 | 80.90% | 306.61 |
| 50 | 0 | 3,453,161 | 896,436 | 1,283,471 | 80.20% | 303.96 |
| Total | 289,441 | 86,329,025 | 20,698,122 | 30,218,781 | | 8,395 |
| | | | | | | |
| 51 | 20,657 | 3,453,161 | 917,993 | 1,306,969 | 97.00% | 367.63 |
| 52 | 0 | 3,453,161 | 940,818 | 1,331,797 | 96.30% | 364.98 |
| 53 | 0 | 3,453,161 | 964,979 | 1,358,017 | 95.60% | 362.32 |
| 54 | 0 | 3,453,161 | 990,550 | 1,385,692 | 94.90% | 359.67 |
| 55 | 0 | 3,453,161 | 1,017,610 | 1,414,889 | 94.20% | 357.02 |
| 56 | 0 | 3,453,161 | 1,046,244 | 1,445,681 | 93.50% | 354.37 |
| 57 | 0 | 3,453,161 | 1,076,544 | 1,478,147 | 92.80% | 351.71 |
| 58 | 0 | 3,453,161 | 1,108,607 | 1,512,367 | 92.10% | 349.06 |
| 59 | 0 | 3,453,161 | 1,142,538 | 1,548,432 | 91.40% | 346.41 |
| 60 | 0 | 3,453,161 | 1,178,451 | 1,586,434 | 90.70% | 343.75 |
| 61 | 331,807 | 3,453,161 | 663,563 | 1,033,556 | 90.00% | 341.10 |
| 62 | 0 | 3,453,161 | 669,375 | 1,039,098 | 89.30% | 338.45 |
| 63 | 0 | 3,453,161 | 675,769 | 1,045,370 | 88.60% | 335.79 |
| 64 | 0 | 3,453,161 | 682,763 | 1,052,386 | 87.90% | 333.14 |
| 65 | 0 | 3,453,161 | 690,373 | 1,060,159 | 87.20% | 330.49 |
| 66 | 0 | 3,453,161 | 698,618 | 1,068,708 | 86.50% | 327.84 |
| 67 | 0 | 3,453,161 | 707,521 | 1,078,049 | 85.80% | 325.18 |
| 68 | 0 | 3,453,161 | 717,103 | 1,088,203 | 85.10% | 322.53 |
| 69 | 0 | 3,453,161 | 727,389 | 1,099,192 | 84.40% | 319.88 |
| 70 | 0 | 3,453,161 | 738,407 | 1,111,038 | 83.70% | 317.22 |
| 71 | 0 | 3,453,161 | 750,185 | 1,123,769 | 83.00% | 314.57 |
| 72 | 0 | 3,453,161 | 762,755 | 1,137,410 | 82.30% | 311.92 |
| 73 | 0 | 3,453,161 | 776,150 | 1,151,994 | 81.60% | 309.26 |
| 74 | 0 | 3,453,161 | 790,406 | 1,167,551 | 80.90% | 306.61 |
| 75 | 0 | 3,453,161 | 805,563 | 1,184,117 | 80.20% | 303.96 |
| Total | 352,464 | 86,329,025 | 21,240,272 | 30,809,023 | | 8,395 |
| | | | | | | |
| 76 | 22,632 | 3,453,161 | 821,662 | 1,201,728 | 97.00% | 367.63 |
| 77 | 0 | 3,453,161 | 838,749 | 1,220,425 | 96.30% | 364.98 |
| 78 | 0 | 3,453,161 | 856,871 | 1,240,250 | 95.60% | 362.32 |
| 79 | 0 | 3,453,161 | 876,082 | 1,261,249 | 94.90% | 359.67 |
| 80 | 0 | 3,453,161 | 896,436 | 1,283,471 | 94.20% | 357.02 |
| 81 | 0 | 3,453,161 | 917,993 | 1,306,969 | 93.50% | 354.37 |
| 82 | 0 | 3,453,161 | 940,818 | 1,331,797 | 92.80% | 351.71 |
| 83 | 0 | 3,453,161 | 964,979 | 1,358,017 | 92.10% | 349.06 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 84 | 0 | 3,453,161 | 990,550 | 1,385,692 | 91.40% | 346.41 |
| 85 | 0 | 3,453,161 | 1,017,610 | 1,414,889 | 90.70% | 343.75 |
| 86 | 0 | 3,453,161 | 1,046,244 | 1,445,681 | 90.00% | 341.10 |
| 87 | 0 | 3,453,161 | 1,076,544 | 1,478,147 | 89.30% | 338.45 |
| 88 | 0 | 3,453,161 | 1,108,607 | 1,512,367 | 88.60% | 335.79 |
| 89 | 0 | 3,453,161 | 1,142,538 | 1,548,432 | 87.90% | 333.14 |
| 90 | 0 | 3,453,161 | 1,178,451 | 1,586,434 | 87.20% | 330.49 |
| 91 | 0 | 3,453,161 | 1,202,501 | 1,618,810 | 86.50% | 327.84 |
| 92 | 0 | 3,453,161 | 1,227,042 | 1,651,847 | 85.80% | 325.18 |
| 93 | 0 | 3,453,161 | 1,252,083 | 1,685,558 | 85.10% | 322.53 |
| 94 | 0 | 3,453,161 | 1,277,636 | 1,719,957 | 84.40% | 319.88 |
| 95 | 0 | 3,453,161 | 1,303,710 | 1,755,058 | 83.70% | 317.22 |
| 96 | 0 | 3,453,161 | 1,330,316 | 1,790,876 | 83.00% | 314.57 |
| 97 | 0 | 3,453,161 | 1,357,466 | 1,827,424 | 82.30% | 311.92 |
| 98 | 0 | 3,453,161 | 1,385,169 | 1,864,719 | 81.60% | 309.26 |
| 99 | 0 | 3,453,161 | 1,413,438 | 1,902,774 | 80.90% | 306.61 |
| 100 | 0 | 3,453,161 | 1,442,284 | 1,941,606 | 80.20% | 303.96 |
| Total | 22,632 | 86,329,025 | 27,865,777 | 38,334,177 | | 8,395 |
| | | | | | | |
| TOTAL | 10,962,324 | 345,316,100 | 89,781,858 | 128,807,065 | | 33,579 |
| | | | | | | |
| | | | | 574,867,347 | | |
| | | | | | | |
| Carbon Neutral | | Total Modules needed | | 68,535 | | $30,292,590 |
| | | | | | | |
| | | Per Array | | 17,134 | | $7,573,148 |
| | | | | | | |
| | | | | | | |
| Net-Zero | | | | 563,905,023 | | |
| | | | | | | |
| | | Total Modules needed | | 67,173 | | $29,690,348 |
| | | | | | | |
| | | Per Array | | 16,793 | | $7,422,587 |